The Impact of Traffic Related Air Pollution in Northern Ireland

Volume 1 of 1

Danielle Magowan
BSc (Hons) Environmental Health
Ulster University

Faculty of Art, Design and the Built Environment of
Ulster University

Thesis submitted for the degree of Doctor of Philosophy

August 2018

(I confirm that the word count of this thesis is less than 100,000 words)

Table of Contents

List of Figures

List of Tables

Acknowledgements

Sincere appreciation is given to the academic staff who gave support and advice during the completion of this thesis. The help and guidance of Dr Marie Vaganay was particularly valued during this time. The support and time she gave during the supervision of this work has been greatly appreciated. I also wish to recognise the support and assistance which Mr Sean MacIntyre and Dr Robert Eadie have provided. There are also support staff within the university who during the completion of thesis have provided assistance and advice, in particular Mrs Irene Moreland and Dr John McGrath. Sincere thanks is also given to my fellow researchers Jill, Karina and Aaron for their friendship and encouragement during the research process.

My family, friends and husband have been an unwavering support throughout the completion of this thesis. My family have provided constant support, encouragement and advice. I greatly appreciate your love and belief in my abilities. My deepest appreciation to my husband John who has supported me in many ways and has always had faith in my ability. Thank you for your encouragement and understanding.

Above all, I acknowledge the One who makes all things possible. Praise and glory be to God for His rich grace and mercy.

Abstract

In Northern Ireland there is a high dependency on private cars to make journeys. This dependency is one of the reasons why several areas currently exceed the legal limit for nitrogen dioxide. Exposure to pollutants emitted from vehicles has been linked to various health effects across all stages of life from the unborn child to the elderly.

There is a large amount of research which has investigated the health impact of exposure to air pollution. Due to the amount of information available and the conflicting results there is some confusion on what the impact of exposure to air pollution is. To contextualise and underpin this research a review of the current literature was completed. Although air pollution is known by professionals to impact on health, the awareness and concern of those who are exposed to air pollution is unknown. Furthermore, the majority of previous research has focused on outdoor air pollution, when the majority of time is spent indoors.

This research investigates three different aspects of traffic related air pollution in Northern Ireland. This includes public awareness and knowledge of air pollution, the indoor and outdoor levels of nitrogen dioxide and the evaluation of local air quality management. To gather the empirical data, a mixed method approach was devised which consisted of questionnaires, interviews and the measurement of nitrogen dioxide levels. During the data analysis stage, SPSS was used to analyse the quantitative data and NVivo was used to analyse the qualitative data.

Several key findings were found from the research which will be useful for policy development and for the future management of air pollution from traffic. There was a low level of awareness among those living in air quality management areas about the levels of air pollution they were being exposed to. The participants who had a greater knowledge of the health impact of air pollution had a higher level of concern about air pollution. There were several areas where the measured level of nitrogen dioxide exceeded the legal level. The local air quality management system has had success in identifying the levels of air pollution but has failed to reduce traffic related air pollution. A new approach is required along with greater public engagement. The

policy and practical implications of the research are outlined. These indicate where future interventions should focus.

Abbreviations

ANOVA- Analysis of Variance

AQMA- Air Quality Management Area

BREXIT- British Exit from European Union

DEFRA- Department for Environment, Food and Rural Affairs

DAERA- Department of Agriculture, Environment and Rural Affairs

LAQM- Local Air Quality Management

NO_2- Nitrogen Dioxide

PM_{10} – Particulate Matter 10

$PM_{2.5}$ – Particulate Matter 2.5

SPSS- Statistical Package for Social Science

WHO- World Health Organisation

Chapter 1: Introduction

Clean air is essential to ensure human health and well- being. Poor air quality has been identified as the single largest environmental risk to public health and well-being (DEFRA, 2017). There are several sources which can contribute to air pollution levels including industry, agriculture, power plants, households and vehicles. Currently one of the main sources of air pollution is road traffic (Environmental Protection UK, 2017). Within the United Kingdom, the number of registered vehicles and the number of miles travelled by car has increased each year. In 2016, there were 30.9 million cars licensed within Great Britain and cars were used for 78% of journeys made by the public (Department for Transport, 2017). Two of the main pollutants from traffic are nitrogen dioxide and particulate matter (DEFRA, 2017).

Exposure to air pollution is not public choice but is often a consequence of daily living. Where people work, where people live and how they travel determines their level of exposure. Air pollution is not a visible problem, cannot be heard or smelt and therefore has been described as an 'invisible killer' (WHO, 2017). Public awareness and perception of air pollution is an important consideration to ensure those most vulnerable can take steps to reduce their exposure. There are many health effects which have been linked to exposure to air pollution from traffic including respiratory illnesses, cardiovascular illnesses, foetal development problems, diabetes and cognitive development impairment. The strongest evidence exists in relation to respiratory and cardiovascular illnesses (Royal College of Physicians, 2016).

In 2015, twenty-two European countries reported exceedances of the annual objective for nitrogen dioxide (EEA, 2017). One of these countries is the United Kingdom where the levels of nitrogen dioxide are still higher than the legal requirement. Each local council is required to review and assess the air quality in their district. If an exceedance of the EU objective level is found for a pollutant, an air quality management area must be declared. Once declared, an annual action plan must be produced outlining the action being taken to reduce the levels of the pollution in the area. There are currently over 700 Air Quality Management Areas

(AQMAs) across the United Kingdom which have been declared due to a failure to comply with objectives set in legislation. From the total number of AQMAs, 618 have been declared for nitrogen dioxide (DEFRA, 2017). Furthermore, it has been estimated that more than 80% of people who live in urban areas subject to air pollution monitoring, are exposed to levels of air pollution higher than recommended within the World Health Organisation Guidelines (WHO, 2016). The UK Government has been taken to the Supreme Court for their failure to comply with European Legislation on air pollution levels (Client Earth, 2017). Client Earth have taken the UK government to court three times due to the Government's failure to provide suitable and achievable plans to reduce nitrogen dioxide levels (CO/1508/2016). Client Earth (2017) have criticised government reports on measures to reduce air pollution by stating that they are merely a '*plan for more plans'*. Concerns have been raised that post Brexit, organisations such as Client Earth will not be able hold the government accountable for failing to comply with European legislation (United Nations, 2017).

The remainder of this chapter focuses on traffic related air pollution and its impact. It introduces the pollutants that are emitted from vehicles and factors which have contributed to an increase of emissions from vehicles. In addition, the impact of exposure on health and the current levels across the United Kingdom are discussed. The chapter concludes with the aim and objectives of the research.

1.1 Traffic Related Air Pollution

Transport is considered the main contributor to air pollution levels within cities (EEA, 2015). In the United Kingdom, vehicles emit more pollution than any other human activity. Those who live in urban areas are exposed to higher levels as the emission density is high and the dispersion conditions can often be unfavourable (Tiwary and Colls, 2010). Car usage and miles travelled have increased each decade within the United Kingdom. In 1950 there were 50 million cars for 3.5 billion people. Currently there are over 600 million cars for 6.7 billion people (Tiwary and Colls, 2010). In Northern Ireland, the number of registered vehicles continues to rise. In 2011, there were 1,053,338 cars registered compared to 1,103,082 in 2015 (Department for Infrastructure, 2016). Furthermore, 72% of journeys were made using a car

(Department for Infrastructure, 2017). This indicates the high dependency on cars for travelling in Northern Ireland.

Passenger vehicles emit several pollutants into the air which contribute to ambient air pollution levels. The two pollutants which have caused exceedances of the legal limits are nitrogen dioxide and particulate matter (DEFRA, 2016). However, there are various other pollutants emitted from vehicles. Each pollutant is discussed below;

- Particulate Matter (PM) - Primary PM is emitted directly into the atmosphere. Secondary PM is formed in the atmosphere after the release of pre-cursor gases such as sulphur dioxide, nitrogen dioxide and VOCs.
- Nitrogen Oxide (NO_x) - a mixture of chemicals which are formed due to the reaction of nitrogen.
- Carbon Dioxide (CO_2) - carbon dioxide and water are the two products from fuel combustion. Carbon dioxide is the main contributor to greenhouse cases.
- Hydrocarbons (HCs) - are produced from incomplete combustion. Hydrocarbons and volatile organic compounds (VOCs) contribute to the formation of ground level ozone which can often lead to a photochemical smog.
- Carbon Monoxide (CO) - product of incomplete combustion. It occurs when the carbon in the fuel is only partially oxidised therefore producing CO rather than CO_2.

The combination of the pollutants is often broadly discussed using the term, 'traffic related air pollution' (TRAP) (EEA, 2016).

The quantity of pollution released from a vehicle is dependent on a number of factors including vehicle type, age, wear of parts, type of fuel and engine lubricants used (WHO, 2013). Driving style can impact on emissions from a vehicle. There are several factors which have been identified as increasing or decreasing levels of pollution emitted. For example, it has been suggested that reducing the speed of a vehicle from 70mph to 50mph allows the driver to anticipate the need to stop and therefore lead to a smoother driving style. In addition, it can results in 25% greater fuel efficiency. Stopping and starting a vehicle leads to the engine using more fuel and

therefore emitting more pollutants. Reducing congestion, reduces the amount of pollution emitted from vehicles. Under inflated tyres create more resistance, this means the engine has to work harder and more fuel is used. Reducing harsh acceleration, braking and avoiding idling all reduce the emissions from a vehicle. Locations with speed bumps, traffic lights and other traffic calming measures can result in cars emitting higher levels of air pollution (Vehicle Certification Agency, 2018).

Within the United Kingdom, road transport is responsible for 80% of NOx emissions, with diesel vehicles emitting the largest proportion of this total (Tiwary and Colls, 2010). Over the past decade, there has been an increase in the number of diesel vehicles in the United Kingdom. The Environmental Audit Committee (2014) state that this increase is the main driver for the current air pollution problem in cities. The reason for this increase is the promotion of diesel being more fuel efficient and 'greener' than their petrol counterparts. Furthermore, the Government enticed buyers by reducing the Vehicle Excise Duty and having company car tax incentives for those choosing low carbon cars which are often diesel (Hitchcock et al, 2014). In Great Britain, the number of registered diesel vehicles in the year 2000 was 3.2 million compared to 12.1 million in 2016 due to a number of factors including lower vehicle excise duty. While some diesel vehicles emit less carbon dioxide, they have been found to produce 22 times more particulate matter and 4 times more nitrogen oxide than the petrol equivalent (Transport for London, 2014). Another factor, which has been attributed to the increase in air pollution from traffic is the testing of emissions from vehicles. All new cars must be tested to meet the Vehicle Emissions Standard (EURO Standard), however experts have found that the tests car makers use do not represent real world driving conditions (ICCT,2014). The International Council for Clean Transportation (ICCT, 2014) found that NOx levels were seven times higher in real driving conditions compared to the levels stated in laboratory tests. The progressively stricter vehicle emission limits have not led to the reductions in nitrogen dioxide that were anticipated (Hitchcock et al, 2014). The scale of the discrepancies between emission limits and actual engine emissions was confirmed when the Volkswagen Audi Group admitted to installing 'defeat devices' in their

vehicles. These devices had the ability to recognise when the vehicle was under test conditions and adjust the engine performance in order to comply with emission limits. This admission lead to an investigation of other car manufacturers and although they had not installed specific devices, a large difference between test emissions and on road emissions was found for the majority of vehicle manufacturers (Coghlan, 2015). The tightening of vehicle emissions standards through the Euro Standards were anticipated to prevent further increases in pollutants emitted from vehicles, however it is evident that manufacturers have failed to produce the reductions required in real world driving conditions. This may have been due to unrealistic timescales to produce the required technology.

1.2 Impact of traffic related air pollution on health

Each year in the United Kingdom it is estimated that 40,000 deaths are attributed to exposure to outdoor air pollution (Royal College of Physicians, 2016). Vulnerable groups such as the elderly, children and those with existing health conditions have been identified as more susceptible to the risks of air pollution (WHO, 2013). The World Health Organisation (2013) have stated that both short term and long term exposure to air pollution is linked to hospital admissions, mortality and respiratory illnesses. These symptoms were more consistently found in those more vulnerable, particularly asthmatics. In addition, the effects were found below the World Health Organisation Guideline for nitrogen dioxide. The World Health Organisation (WHO, 2013) concluded that there is a link between nitrogen dioxide and various health effects, however it is not strong enough to determine causality. The US Environmental Protection Agency (EPA, 2015) also came to the same conclusion after completing a recent analysis of evidence.

In addition, research suggests exposure to particulate matter and a mixture of traffic related air pollution can impact on health (WHO, 2012., RCP, 2016). The International Agency for Research on Cancer has classified diesel engine exhaust emissions, outdoor air pollution and particulate matter as carcinogenic to humans (WHO, 2012). There are also various other health conditions which have been linked to exposure

such as diabetes, pregnancy complications and cognitive health problems (RCP, 2016).

Whilst it appears evident that air pollution emissions from vehicles can impact on the health of the public, the focus of the majority of research on traffic related air pollution is on the impact of ambient levels (McAdam et al, 2011., Tabaku et al, 2011; Gallagher et al, 2013; Gatto et al, 2014; Lui et al, 2015; Chen et al, 2016). It is estimated that the majority of people spend more time indoors. University of York (2015) have estimated that 90% of time is spent indoors. Consideration needs to be given to the impact of traffic related air pollution on indoor air quality due to the amount of time that is spent there.

1.3 Air Pollution in United Kingdom

There are widespread exceedances of the objective (40 µg m^{-3}) for nitrogen dioxide throughout the United Kingdom. The United Kingdom is divided into 43 zones and agglomerations for reporting air pollution levels under European Legislation. Currently 37 of these zones are exceeding the annual objective for Nitrogen Dioxide. The annual mean objective in European legislation was to be met by 2010 yet it has still not been achieved. A time extension was granted for 13 zones for compliance to be achieved by 2015. However now 2 years post the extension, the majority of these areas are still non-compliant (DEFRA, 2016). The objectives have been set to protect public health and well- being. With the objectives not being met the public are being exposed to air pollution levels which are potentially harmful to health.

1.4 Air Pollution in Northern Ireland

Under the Environment Order (NI) 2002, District Councils are required to assess the levels of certain pollutants. If an exceedance is found they are required to declare an Air Quality Management Area (AQMA) (DEARA, 2016). The legislation governing air pollution in Northern Ireland will be discussed in more detail in Chapter 2. Currently in Northern Ireland there are 26 AQMAs. Of these 26, 19 are declared due to nitrogen dioxide emissions from road traffic (DAERA, 2016). There are currently 19 automatic monitoring stations within Northern Ireland with 16 of the stations

monitoring for nitrogen dioxide. In addition to the automatic monitoring stations, diffusion tubes are used to measure levels on a wider basis (DAERA, 2016). The most recent report (DAERA, 2016) on air pollution in Northern Ireland was produced in 2016 which reviewed the air pollution data collected in 2015. In 2015, two of the automatic monitoring stations (Stockmans Lane, Belfast and Marlborough Street, Londonderry) exceeded the 40µg m^{-3} annual mean objective for nitrogen dioxide. Since the introduction of Local Air Quality Management in Northern Ireland in 2002, 15 years ago, there have only been two Air Quality Management Areas (Ballyclare and Sandyknowes) revoked due to reductions in the levels of nitrogen dioxide (DAERA, 2017). Given the lack of progress to date, the effectiveness of the LAQM regime at reducing traffic related air pollution needs to be considered.

Air pollution has been included in the Draft Programme for Government 2016-2021 (Northern Ireland Executive, 2016) indicating that the government are aware it is an area which needs to be addressed in Northern Ireland. The programme acknowledges the need to consider the environment while encouraging economic growth. There are a number of actions which have been drafted in in order to achieve a reduction in air pollution including promoting electric vehicles and creating an air quality action plan (DEFRA, 2017).

It is evident that air pollution specifically from traffic needs to be addressed within Northern Ireland. If the trend of increasing registered vehicles and miles travelled continues to increase, air pollution levels will continue to rise. Consideration needs to be given to identifying the impact which exposure to pollutants from traffic is having on the residents of Northern Ireland. Understanding the local impact, can be the driver required for change to occur.

1.5 Aim

The overarching aim of this research is to identify public awareness and perception of air pollution and to establish the indoor and outdoor levels of nitrogen dioxide from traffic. The research also aims to review the current Local Air Quality

Management regime and make recommendations for future practice. The aim is summarised below;

- Establish the level of concern and knowledge about traffic related air pollution among those who are exposed to the highest residential levels
- Identify exposure to indoor and outdoor levels of nitrogen dioxide
- Review the current Local Air Quality Management system

1.6 Objectives

To meet the aims of the research, the following objectives have been set:

- To identify and review the current evidence on the health effects associated with exposure to air pollution, in particular the pollutants associated with road traffic
- To identify public perception, awareness and knowledge of road traffic related air pollution
- To establish the health impact of living near a road that exceeds air quality guidelines for nitrogen dioxide
- To establish the current levels of traffic related nitrogen dioxide, indoor and outdoor, on several roads in Northern Ireland
- To evaluate the Local Air Quality Management Regime and identify measures for future improvement

1.7 Research Questions

The research will address the following research questions:

- What evidence is available on the health effects associated with exposure to traffic related air pollution?
- What are the current levels of roadside nitrogen dioxide in Northern Ireland and how do they impact on indoor levels of air pollution?
- Are the public concerned about air pollution? Are they aware of the potential health impacts?

- What action is currently being taken to reduce traffic related air pollution and is it effective?
- Are current communication methods effective at providing air pollution information to the public?

1.8 Research Approach

The methodology was designed to meet the aims and objectives of the research. Three studies were completed and a summary of each is provided below.

- Study 1 comprised of a questionnaire which was completed in AQMAs. It aimed to identify participant concern, knowledge and awareness of air pollution in their area. It also gathered information on the current health status of the householders.
- Study 2 measured the indoor and outdoor levels of nitrogen dioxide. This was completed to identify residents' exposure to traffic related air pollution.
- Study 3 comprised of interviews with local councils and local residents. These aimed to identify the effectiveness of local air quality management (LAQM) in Northern Ireland and how air quality information is communicated.

The research specifically focuses on nitrogen dioxide for several reasons. Nitrogen dioxide is widely recognised as a marker for traffic related air pollution (HEI,2010., WHO,2013). It is also the pollutant in Northern Ireland which has the most areas of exceedance. In addition, when considering monitoring of pollutants, there is low cost monitoring options.

1.9 Thesis Outline

Chapter One introduces traffic related air pollution. The current situation in Northern Ireland is highlighted and the current statistics on exposure and health impact. The aims and objectives for the research are stated.

Chapter Two provides an overview of the current legislation in place to control air pollution. The overview states the legal objectives which all European Countries are required to meet. In addition, the responsibility of local councils to monitor, control

and manage air pollution is outlined. A critical review is completed of the current Local Air Quality Management Regime.

Chapter Three critically reviews the current literature on traffic related air pollution and the impact on the public. The chapter considers three aspects of air pollution and its impact on people including; public exposure, the health impact of exposure and public awareness and perception of air pollution. The strength of the current available evidence is reviewed and a comprehensive list of the health effects is compiled. Consideration is given to whether current legislation on the acceptable levels of air pollution is effective at protecting health. Furthermore, the chapter considers public awareness, perception and concern about traffic related air pollution. The chapter also identifies human activity patterns and the microenvironments where exposure to traffic is most likely. An overview of the current literature on indoor and outdoor air pollution is included. The chapter provides a summary of the gaps in current literature in relation to traffic related air pollution.

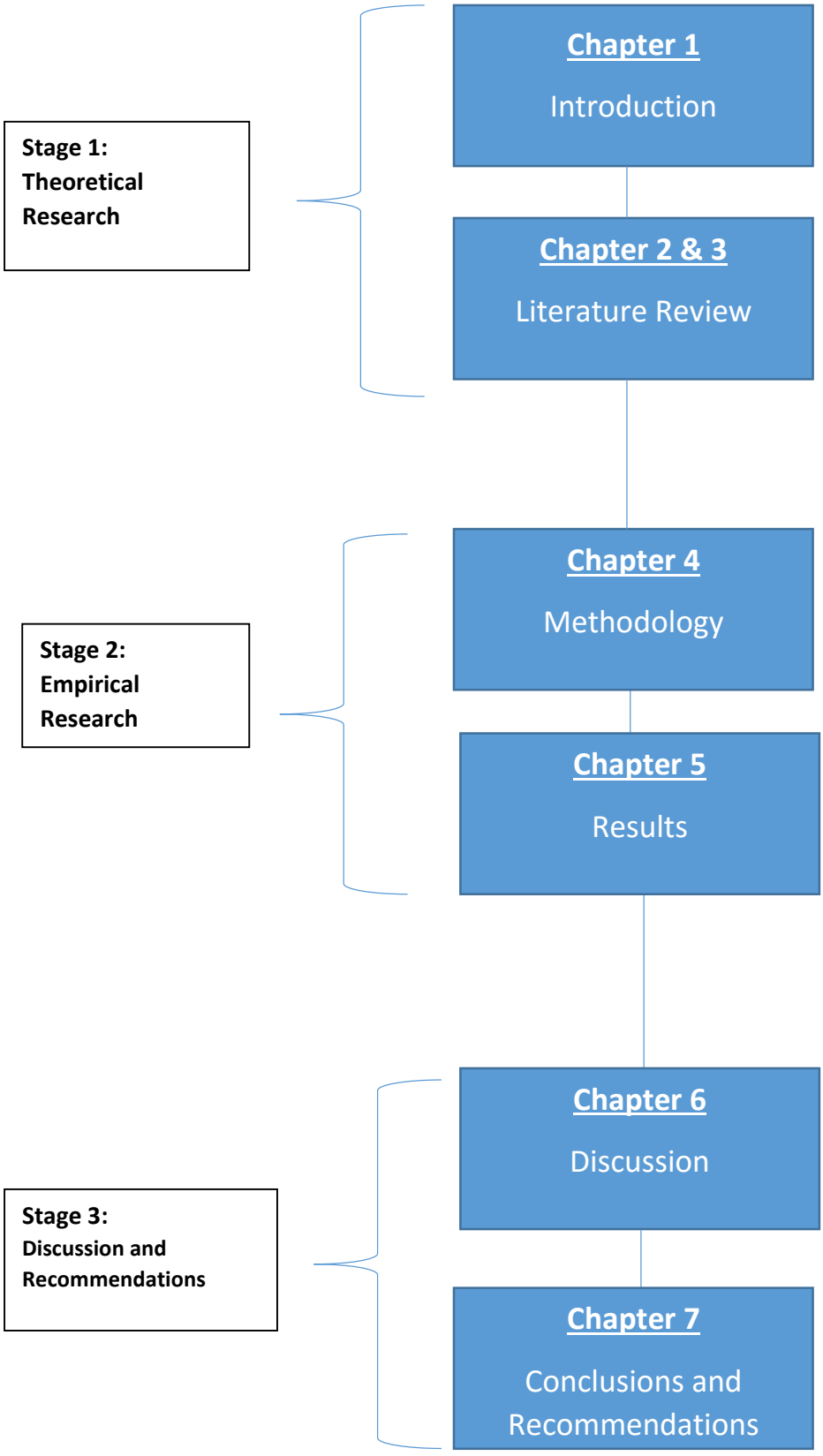
Chapter Four states the research methodology. The methods used in previous research are identified and the suitability of several research methods is reviewed. The details of all studies within the research and their contribution to achieving the aims of the research are stated.

Chapter Five presents the results of each study. Graphs and tables are used to illustrate the results.

Chapter Six discusses the findings of each study with current published literature. The contribution of the research to the current field of traffic related air pollution is stated and the implications for future practice are discussed. The limitations of the research are identified and the strategies put in place to reduce their impact are stated.

Chapter Seven is the final chapter and therefore provides a summary of the findings and the implications of the research. Recommendations are made for both policy and practice. Future work to contribute to the current body of knowledge will be suggested. The thesis structure is illustrated in **Figure 1**.

Figure 1: Thesis Outline



Chapter 2 – Local Air Quality Management

2.1 Introduction

Air Pollution has been a problem within the United Kingdom for decades with different sources being the cause of elevated levels (Barnes et al, 2015). Chapter 1 outlined that road traffic is currently the main source of non-compliance with air quality objectives within the United Kingdom and that a proportion of the population are exposed to levels of air pollution above the recommended limit (DEFRA, 2016). The impact of exposure to high levels of traffic related air pollution on health will be reviewed in the Chapter 3. The levels of Nitrogen Dioxide have decreased since 1990 however over the last 5 years the rate of reduction has slowed (DEFRA, 2015).

Local Air Quality Management has been in place for over 15 years yet there are still exceedances of air quality objectives. Currently 38 of the 43 zones and agglomerations in the United Kingdom are exceeding the EU limit value for nitrogen dioxide which was to be achieved by 2010 (DEFRA, 2015). Consequently, the United Kingdom government has been taken to Supreme Court due to their failing to meet the requirements of EU legislation (Williams et al, 2016). It is evident that the current air pollution management system in the United Kingdom has failed to reduce levels of nitrogen dioxide to an acceptable level.

Legislation has been created to ensure air pollution levels are identified and controlled. This chapter explores the historical development of the current legislation in the United Kingdom and the existing measures in place to reduce air pollution levels. A review of how successful the current local air quality management system is in reducing traffic related air pollution is completed. Furthermore, consideration is given to how air quality should be managed in the future.

2.2 Aims and Objectives

This chapter aims to:

Review the current literature available on air quality management and how this can be used to inform future practice.

This aim will be achieved by meeting the following objectives;

- Outline the current legislation in place governing the management of air pollution in Europe and the United Kingdom
- Critically review the current literature available on the implementation of Local Air Quality Management
- Identify and review the current measures other European and Non-European countries have implemented to reduce air pollution caused due to traffic
- Identify the current gaps in literature to inform future practice

2.3 Development of legislation

Legislation in the United Kingdom is presently based on directives from the European Union (DAERA, 2016). The following sections reflect on the current legislation in place and its role in reducing and managing air pollution.

2.3.1 Development of Legislation in the European Union

In 1996 the European Council Directive 96/62/EC on Ambient Air Quality Assessment and Management was introduced for all member states. Under the framework each country was required to designate a '*competent authority*'. This authority would be responsible for accurately assessing the air quality and reporting the data. Within the UK the competent authority is the Department of for Environment, Food and Rural Affairs (DEFRA). The responsibility for air pollution is shared with the devolved administrations in Scotland, Wales & Northern Ireland (European Parliament, 1996).

Directive 2008/50/EC on Ambient Air Quality and Cleaner Air for Europe contains legislation for several pollutants including sulphur dioxide, nitrogen oxides, particulate matter, lead, carbon monoxide, benzene and ozone. In relation to traffic, the pollutants of most concern are nitrogen dioxide and particulate matter. **Table 1** and **Table 2** outline the objectives for these pollutants. The directive outlines monitoring and modelling techniques which should be used to assess air pollution. In addition, it sets objectives for European counties to meet and requires them to produce action plans if these are not met. Countries are also required to ensure the public and relevant organisations are informed about air pollution. Below **Table 1**

states the requirements of the directive for nitrogen dioxide and particulate matter (European Parliament, 2008).

Table 1: Objectives for Nitrogen dioxide and Oxides of Nitrogen

	Hourly limit value for the protection of human health (NO_2)	**Annual limit value for the protection of human health (NO_2)**	**Annual critical level for the protection of vegetation and natural ecosystems (NO_x)**
Upper assessment threshold	70 % of limit value (140 µg/m³, not to be exceeded more than 18 times in any calendar year)	80 % of limit value (32 µg/m³)	80 % of critical level (24 µg/m³)
Lower assessment threshold	50 % of limit value (100 µg/m³, not to be exceeded more than 18 times in any calendar year)	65 % of limit value (26 µg/m³)	65 % of critical level (19,5 µg/m³)

Table 2: Objectives for Particulate matter (PM_{10}/$PM_{2,5}$)

	24-hour average PM_{10}	**Annual average PM_{10}**	**Annual average $PM_{2,5}$**
Upper assessment threshold	70 % of limit value (35 µg/m³, not to be exceeded more than 35 times in any calendar year)	70 % of limit value (28 µg/m³)	70 % of limit value (17 µg/m³)
Lower assessment threshold	50 % of limit value (25 µg/m³, not to be exceeded more than 35 times in any calendar year)	50 % of limit value (20 µg/m³)	50 % of limit value (12 µg/m³)

(Source for Table 1 and 2: European Parliament, 2008)

A rise in vehicles across Europe lead to an increased need to regulate the emissions from vehicles. The Luxembourg Agreement (88/76/EEC) introduced restrictions on emissions from vehicles which is now known as the Euro Standards. The standard initially focused on the reduction of emissions of lead to the atmosphere which resulted in the widespread use of unleaded petrol (Longhurst et al, 2009). The standard has been updated several times, with the most recent in 2016. All new cars are expected to meet the standard before being approved for sale in the European Union. Regulation (EU) 2016/427 introduced the Euro 6 Standard for light passenger and commercial vehicles. The standard was expected to widely reduce the emissions from transport. However, in 2013, traffic was the main contributor nitrogen oxide emissions in the European Union and accounted for 46% of total emissions (European

Commission, 2016). Although stricter Euro standards have been introduced, the level of nitrogen dioxide has not fallen as much as predicted. The reason for this is the discrepancies between test conditions and real world driving conditions. Research by the International Council on Clean Transportation (2014) found that emissions in the real world were up to seven times higher than the standard set in Euro 6. In 2015, Volkswagen confirmed that they had installed devices in their vehicles which caused the car to behave differently in testing conditions compared to real world driving conditions. To ensure manipulation of testing was not a common feature in car manufacturing the government commissioned a report into all car manufacturers and the testing process (Department for Transport, 2016). The research found that no other manufacturer had installed defeat devices however for all manufacturers vehicles were found to have higher emissions during real world driving (Department for Transport, 2016). Another reason includes the government's decision to reduce vehicle excise duty for cars with low carbon emissions. This decision was made to reduce climate change but has had a detrimental impact on air pollution levels. Low carbon options are often diesel which emit more particulate matter and nitrogen than the petrol equivalent (Hitchcock et al, 2014). This is one of the reasons given by the UK government for failing to meet air quality objectives. For the levels of nitrogen dioxide and particulate matter to decrease further technological advances in vehicle emissions are required.

Due to pressure from environmental groups, academics and the media, a new vehicle testing system is due to be introduced in September 2017. The Real Driving Emissions Test (RDE) is expected to better reflect the emissions released when driving in the real world (European Commission, 2016). European legislation has been influential in the development of air quality standards and vehicle emission controls. The United Kingdom is currently in the process of exiting the European Union. During this transition period, it is important that air pollution control and management remains in place.

2.3.2 Development of Legislation within the United Kingdom

The Clean Air Act was introduced in 1956 in response to the London Smog of 1952 (HM Government, 1956). This first attempt to control air pollution did not mention

concentration guidelines or consider the impact of exposure. The Act focused on domestic coal burning encouraging residents to burn smokeless fuel or switch their heating source to gas, oil or electricity. The Act was successful in reducing the consumption of coal (Longhurst et al, 2009). As emissions from coal burning were beginning to be controlled, a new source of air pollution was beginning to emerge. The number of registered vehicles began to increase and this was coupled with an increase in the number of kilometres travelled by the public (Longhurst et al, 2009).

In response to the European Directive and the Environment Act 1995, the United Kingdom's first Air Quality Strategy was created in 1997. The strategy introduced local air quality management to local government. This involved assessing air pollution levels, reducing public exposure and introducing local reduction measures in order to comply with the Air Quality Objectives. The Air Quality Strategy has been updated three times from its original publication. The first strategy was published in 1997 with revisions made in 2000, 2003 and the most recent being in 2007 (DEFRA, 2007). It has now been 10 years since the strategy has been updated which is longest interval thus far. The current Air Quality Strategy for England, Wales and Northern Ireland communicates the air quality objectives and the policy options for reducing public exposure to air pollution. The strategy was developed in consultation with experts including representatives from the transport sector, industry, local authorities, environmental groups, health experts, researchers and the public. The strategy suggests action should be taken at three levels to reduce air pollution levels including local level, national level and international level. It recognises that the objectives cannot be achieved by one measure but a combination of different measures including technological measures, behaviour change and incentives. The strategy describes each pollutant by explaining the main sources in the United Kingdom and the potential impact on health and the environment. The objectives set in the air quality strategy are described as 'policy targets'. There is no legal obligation to achieve them (DEFRA, 2007). The strategy has now been implemented for 10 years with no updates. Within this time period technological advances have been made and research completed which could have influenced the practice of air quality management. For objectives to be met and a reduction in exposure to air

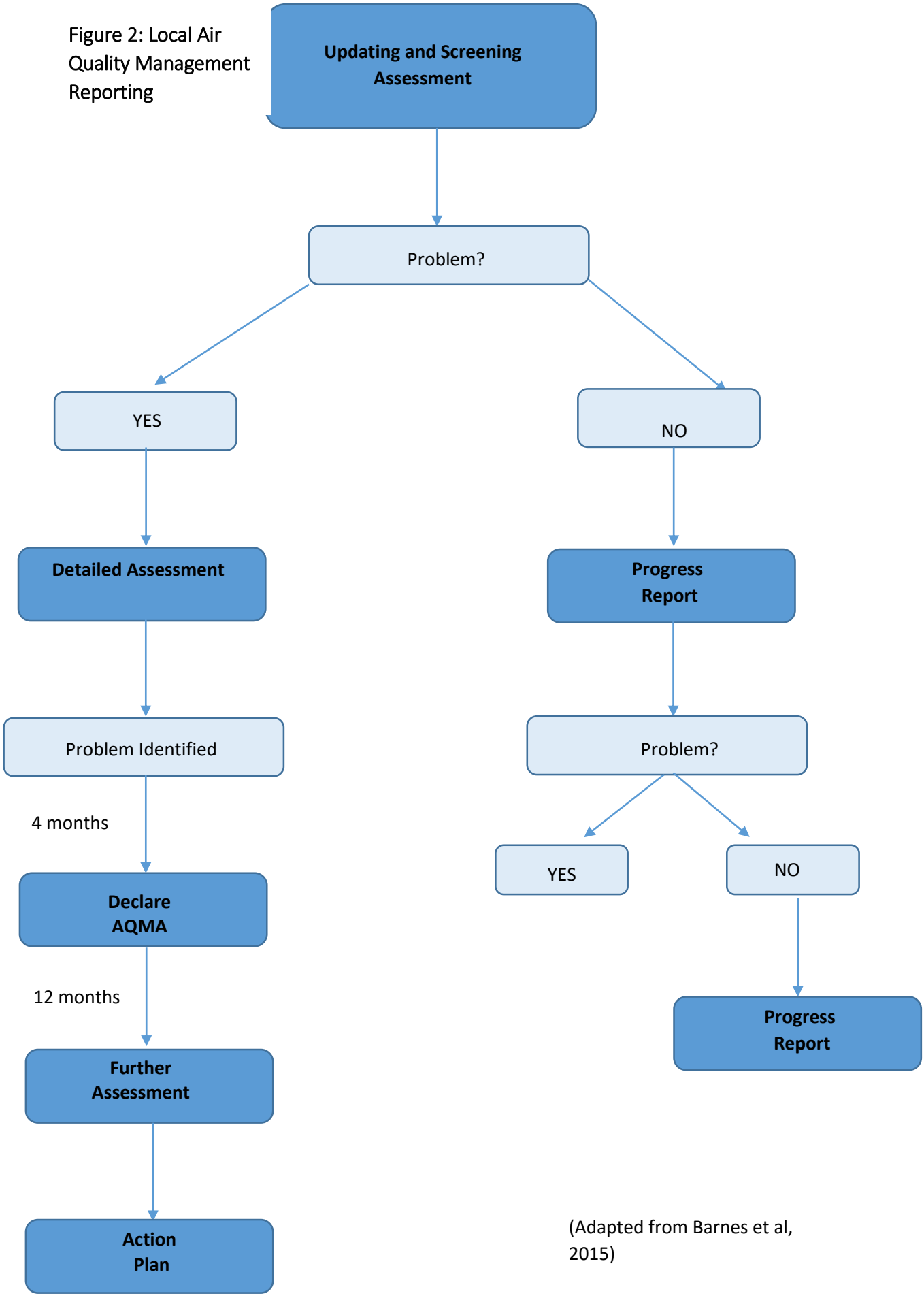
pollution to be achieved, updating the strategy to include the latest evidence would be beneficial.

2.3.3 Development of legislation in Northern Ireland

The Environment (NI) Order 2002 was introduced to fulfil the requirements of European Directive 96/62/EC. The legislation requires district councils to review the air quality in their district and assess whether the objectives have been achieved or are likely to be achieved. The legislation also requires that any area which does not meet or is unlikely to the meet the objectives is to be declared as an Air Quality Management Area (AQMA). The district council is required to complete an Updating and Screening Assessment (USA). This procedure assesses the likelihood of exceeding the air quality objectives. If a risk of an exceedance is found, a Detailed Assessment is then required. This assessment involves the use of validated monitoring and modelling to give an in depth description of the risk. When completed and a risk of not meeting the air quality objectives is found and there is a risk of public exposure, a district council is required to declare an AQMA. Within 18 months of the declaration, district councils are required to produce an Action Plan. The plan should include the proposed actions the council intends to take to reduce air pollution and the date by which the action will be completed (HM Government, 2002). To monitor progress, district councils with AQMAs should complete an annual progress report. The review and assessment stage is on ongoing process. Updating and Screening Assessments are to be completed every three years (DAERA, 2016). The process of reporting is outlined in **Figure 3.**

The air quality legislation in Northern Ireland is based upon the requirements of European legislation which provides a framework for the management of air pollution levels (DAERA, 2016).

Figure 2: Local Air Quality Management Reporting



(Adapted from Barnes et al, 2015)

The Air Quality Standards Regulations (Northern Ireland) 2010 provides detail on the monitoring requirements for various air pollutants. It sets requirements for fixed sites and background monitoring. In addition, it gives detail on what should be included within action plans. The Action Plan should be completed in consultation with other departments and the measures included within the plan should achieve the air quality objectives within the shortest amount of time. The regulation also states that the public should be consulted during the process of developing an action plan and any information received should be considered (HM Government, 2010). Consultation should be seen as an important part of the process as it is thought to increase political and social support for the decisions made (Longhurst et al, 2009). The department is also required to provide the public with the following information; hourly or daily concentrations of nitrogen dioxide, sulphur dioxide and particulate matter (PM_{10}), information when the level of pollution is expected or has exceeded the alert or threshold limit. The Department must publish an annual report detailing the monitoring which has been completed and the pollutants which have exceeded the limits (HM Government, 2010).

From reviewing the history of air pollution management, it is evident that legislation is required before action is taken and real change occurs. This was seen through the Clean Air Act which was successful in reducing the amount of coal being used. In addition, technological advances have shown to be influential in reducing air pollution levels. Coal burning was not reduced until residents were encouraged to use oil or gas and lead levels in the atmosphere were only reduced through the introduction of unleaded petrol (Longhurst et al, 2009). From a historical perspective it is evident that changing the public's behaviour has only been possible after technological advances have created a suitable alternative. This may too be the case for reducing traffic related air pollution. Increasing the proportion of electric vehicles on the road may be one of the technological advances required to reduce traffic related air pollution.

2.4 Local Air Quality Management (LAQM)

The Local Air Quality Management system was introduced in 1997 as a framework to assess and manage air pollution. During this time air pollution levels have improved,

however there are still areas where the air quality objectives are still exceeded. Currently there are 620 Air Quality Management Areas in the United Kingdom which indicates there still needs to be improvements made (DEFRA, 2015b). The review below considers the strengths and weaknesses of the current system and how these can be used to improve future practice.

2.4.1. Review of Local Air Quality Management

Since the inception of Local Air Quality Management there have been several reviews completed to evaluate its success in reducing air pollution levels. The majority of the research in this area has been carried out by small number of researchers therefore should be viewed with some caution.

2.4.1.1 The principles of the management system

Local Air Quality Management has provided a framework for action for local authorities to follow to meet the requirements of the legislation. Furthermore, to enable local authorities to meet the requirement they have received funding for monitoring. If the monitoring and managing air pollution was not a legal requirement, local authorities may not have received the financial support to improve air quality (Longhurst et al, 2009). The monitoring of air pollution has led to the identification of 'hot spot' areas of air pollution.

The LAQM process is based upon risk assessment principles. Local Authorities are required to assess air pollution in relation to the risk it poses to the public. The air quality objectives which have been established are based on scientific evidence on the health impact of certain pollutants (Brunt et al, 2016). Concerns have been raised by professionals on the ability of LAQM to protect health. This in particular relates to the level of particulate matter ($PM_{2.5}$). Health effects have been found at levels below the concentrations stated in the Air Quality Objectives. The Objectives need to be reviewed more frequently in line with new published evidence. This has been discussed in greater detail in **Chapter 3**.

Local Air Quality Management recognises the difference between local and national action which can viewed as both a strength and weakness. The air pollution that is emitted locally, is best managed by local professionals who understand the area and can identify suitable management measures (Welsh Government, 2016). However,

Carmichael and Lambert (2011) state devolving power to local authorities may cause people to believe that air pollution and its impact on health is of lower importance. Some individuals may believe that the most important decisions are made at central government level therefore by devolving power to local authorities, the government is indicating their view on the importance of air pollution. In addition, devolving responsibility has been found ineffective as local authorities lack the powers needed to implement required reduction measures (Barnes et al, 2014). For example, in relation to traffic related air pollution, a change in the road layout may be the most effective action to reduce air pollution levels. However local authorities do not have the budget or powers to implement such a change.

Currently 62% of Local Authorities have Air Quality Management Areas. There are currently 585 AQMAs across the United Kingdom which have been declared due to traffic related air pollution. Since the inception of LAQM there have been 79 traffic related AQMAs in the United Kingdom which have been revoked (DEFRA, 2017). This indicates that in over ten years of implementation of LAQM, 10% of the AQMAs which were declared for road traffic are now revoked. The overall effectiveness at reducing the levels of traffic related air pollution in these areas has been low. The process has identified high pollution areas but large reductions have not yet been achieved (Barnes et al, 2015).

2.4.1.2 The process of implementing LAQM

2.4.1.2.1 Consultation with stakeholders

One of the requirements of LAQM is to consult with statutory and non- statutory stakeholders. Current literature has identified a number of barriers which have hindered the success of the consultation process. Firstly, the lack of consideration some departments give to the consultation. For example, Dorfman et al (2006) states the process if often regarded as a 'tick box' exercise which means a significant contribution is often not achieved. Secondly, local authorities identified lack of training in how to conduct effective consultation as a barrier for success. Furthermore, the lack of a set procedure or mechanism for consulting with other departments and organisations has been identified as a barrier. Facilities to co-ordinate with other professionals should be set up and greater integration of

departments should be considered (Jones and Longhurst, 2010., Welsh Government, 2016). Further information on the type of consultation completed is required. This would allow for the identification of the most effective method. The lack of regular communication within local authority departments (Beattie et al, 2001) and with external organisations (Longhurst, 2006; Jones and Longhurst,2010) has been identified as an issue. A case study conducted in a local authority in England found that air quality information was poorly disseminated among other departments. Other departments state that they rarely received information on air pollution in the area. In addition, when information was received, the recipients did not find the material to be informative (Jones and Longhurst, 2010). It is evident from the literature presented that local authorities need to develop a better system for communicating and consulting with other departments and organisations.

Air pollution is a diverse issue which cannot be resolved through the work of one department therefore measures to reduce air pollution often involve more than one government department. Local Authorities are required to produce action plans with measures to reduce air pollution. Many action plans suggest measures which are to be implemented by other departments both within central and local government. The success of the measures outlined in action plans is reliant on other departments appreciating the importance of reducing air pollution. Furthermore, it also dependent on those departments having the necessary budget and authority to implement the suggested changes (In House Policy Consultants, 2010; Barnes et al, 2015). Barnes et al (2015) found that collaboration between environmental health departments and other government departments in relation to action planning is low. For this to improve, national policy and legislation need to interconnect (Barnes et al, 2015). Many local authorities in England state they have little support in developing or implementing actions plans (Hayes, 2009 In House Policy Consultants, 2010; Olowoporoku et al, 2012).

2.4.1.2.2 Consistency

The guidance (Local Air Quality Management Policy Guidance 2016) was produced to ensure a consistent approach for the assessment of air pollution levels. It includes a monitoring and modelling procedure. Concerns have been raised that the guidance

is being applied inconsistently therefore providing an inaccurate picture of the current air pollution situation in the United Kingdom (Woodfield et al, 2003). Inconsistency is also found in boundary setting for air quality management areas. AQMAs can range from one street to whole town or city (Longhurst et al, 2009).

2.4.1.2.3 Reporting Requirements

There have been several reviews commissioned by DEFRA to obtain the views of those working in Local Authorities about the effectiveness of the process of LAQM. The response rate for these questionnaires are high however this may be influenced by the Government issuing the questionnaire. Although LAQM was introduced so air pollution could be managed at local level, the research found many professionals find the process to be too centrally driven and requires an excessive amount of reporting (In house Policy Consultants, 2010). In response to this the government has introduced Action Planning in England and Scotland which in theory should reduce the amount to reporting required. This has not yet been introduced in Northern Ireland. Local Authorities are required to submit their reports to DEFRA by April each year however many reports are not submitted on time therefore reducing the efficiency of the system (Welsh Government, 2016). Reducing the scale of reporting may help to reduce this issue.

Local Air Quality Management aims to ensure that the public have access to clean air without a major risk to health. LAQM is designed as a risk based process by assessing the air quality against the objectives set out in legislation and based on scientific evidence. Reviews of action plans have found that the public health aspect is often not the main consideration when developing an action plan (Chatterton et al, 2007). Brunt et al (2016) found that basic metrics such as number of people living within an AQMA were inconsistent. In addition, the current review process does not require any quantification of public health burden in the area, which should be key to the decision making process (Brunt et al, 2016).

Barnes et al (2015) found after reviewing action plans of several local authorities in England that LAQM was an unsuccessful strategy to achieve the air quality objectives and EU limit values set in legislation. The main failing identified was the inability to measure the progress of LAQM in reducing the levels of air pollution. This is further

reiterated by Longhurst et al (2010) who found that Local Air Quality Management is strong on diagnosing the air pollution problem but fails to provide solutions to tackle it.

The focus of the research included within this literature review has been the implementation of Local Air Quality Management in England, Scotland and Wales. No previous research has reviewed the effectiveness of the process within Northern Ireland. There are several differences between the implementation in Northern Ireland including a different reporting system from England. In addition, Northern Ireland is a devolved administration and has different departments to consult with compared to the other part of the United Kingdom. The structure of the local councils is also different to the authorities in England. Furthermore, Northern Ireland has a more dispersed settlement pattern which has resulted in a greater dependency on private car use.

2.4.1.3 The Outcome of LAQM

The process of assessing air quality and declaring an Air Quality Management Area has remained unchanged from its commencement in 1997 (Longhurst et al, 2016; Brunt et al, 2016; Barnes et al, 2014; Longhurst et al, 2009). In the United Kingdom the first Air Quality Action Plans were completed in 1999. Almost 17 years later, 60% of local authorities have at least one Air Quality Management Area, with the main source being identified as traffic (Barnes et al, 2014). Despite over a decade of Local Air Quality Management, Moorcraft and Dore (2013) found no evidence that an AQMA declared due to traffic has been revoked by the implementation of the local authorities Action Plan. However, it has been noted by Barnes et al (2015) that linking a reduction in the level of nitrogen dioxide with a measure from an air quality action plan is problematic. There are several factors which can influence the level of nitrogen dioxide for example wind speed and direction. Therefore, calculation of the impact of a measure can be difficult due to the cumulative effect of different influencing factors. In addition, often automatic monitoring stations are not situated to be representative of the AQMA therefore making an assessment of progress can be difficult (Barnes et al, 2015). For example, an AQMA which encompasses a whole city may only have one or two automatic monitoring stations. The recordings from

these stations are not representative of every street within the city. If a reduction measure is introduced several streets from the monitoring station, the impact on air pollution levels is unlikely to be recorded by the monitoring station (Welsh Government, 2016). Many Local Authorities have been relying on air pollution levels to be reduced from the stricter euro standards on emissions from vehicles. However, this has failed which has led to an increase in air pollution in many areas. The advancement in emission technology which local authorities were relying on to reduce levels has failed due to vehicle emissions testing not being representative of real world driving conditions therefore leading to higher than expected emissions (ICCT, 2014). In addition, each year there is an increase in registered vehicles (Welsh Government, 2016). Furthermore, there are many confounding factors such as weather conditions and traffic flow which make assessing progress challenging. These factors are discussed in greater detail in Chapter 3 **Section 3.2.5**.

Measures outlined in air quality action plans often have at least one measure which involves behaviour change from members of the public. Action plans are readily available from most local authority websites, however they are ineffective at describing the current air pollution problem in a manner which can be easily understood by non-experts (Barnes et al, 2014). To initiate the behaviour change, knowledge is required to empower individuals (Environmental Audit Committee Report, 2009). A review of the current information available to the public, both from local authorities and central government, should be completed.

The lack of easily understood information may contribute to the lack of political support for air quality issues which has been identified as another barrier which impacts on the implementation of LAQM measures. Plans to increase the economic development of an area can often be in conflict with environmental policy. Politicians often favour the economic and social benefits rather than considering the wider impacts of increased development (Campbell and Green, 1996; Jones and Longhurst, 2010; Olowoporoku et al, 2010). These previous reviews have focused on political support in England. This aspect should be considered in Northern Ireland which has its own devolved government and therefore can set its own local priorities which may positively or negatively impact on air quality control.

As can be seen from the above information there are both strengths and weaknesses found in the current Local Air Quality Management system. These are summarised below;

Strengths

+ LAQM provided local authorities with a framework for action
+ Identified areas with high levels of air pollution
+ It is based on risk assessment principles
+ Local Authorities received funding to complete the work as it was a legal requirement

Weaknesses

- Lack of support or action from other government departments
- Lack of powers to put in place required actions
- Ineffective consultation with other departments
- Excessive reporting requirements
- Lack of political support
- Little progress achieved in reducing levels

The EU Limit Value for Nitrogen Dioxide was to be achieved by 2010 yet 38 of the 43 zones and agglomerations were still exceeding the value in 2016. As a consequence to the non-compliance, the government were ordered by the Supreme Court to submit a new Air Quality Action Plan which would achieve the objectives within the shortest amount of time (Williams et al, 2016). Some of the failings can be attributed to the ineffective application of the requirements such as consultation with stakeholders and inconsistency in applying the guidelines. The inability to fully measure the progress of implementing action plans reduces motivation and support. The research completed on evaluating the Local Air Quality Management system is completed by a small team of researchers. The research is also limited to certain parts of the United Kingdom. The majority of the research completed focuses on the impact on air pollution in England or Scotland. A review of the effectiveness in Northern Ireland is required.

2.4.1.4 Recent Developments in the United Kingdom Air Quality Management

Due to the inefficiencies mentioned in the previous section in regard to Local Air Quality Management, it seems likely that changes to the current system need to occur for a reduction in the level of nitrogen dioxide to be achieved. This has been recognised in both Wales and Scotland who have conducted a review and consultation period in regard to new air quality management regimes.

In Wales, a recently published document, 'Local Air Quality and Noise Management in Wales' is currently under consultation (Welsh Government, 2017). The emphasis on completing the review and producing a document was to ensure the public receive the same level of protection from harmful pollutants after leaving the European Union. The document outlines the key components which must remain. The document proposes that a more collaborative and integrated approach is used in the future of air quality management. This is firstly suggested through integrating noise and air pollution management. The rationale for this change is due to noise and air often being emitted from similar sources for example traffic and industry. The document also suggests air pollution control should be more widely implemented rather than action plans focusing on reducing air pollution only in Air Quality Management Areas. This action is taken due to recently published evidence that there is '*no safe*' exposure level to certain pollutants. The Welsh Report (Welsh Government, 2017) states that the population are often exposed and in certain areas, spend more time outside Air Quality Management Areas. The belief is that reducing pollution levels more widely will create a wider public health benefit (Welsh Government, 2017). This will push local authorities to look at air pollution more broadly rather than just achieving compliance. One of the difficulties with Local Air Quality Management was the lack of collaboration and partnership working. Under new legislation in Wales (Wellbeing of Future Generations (Wales) Act 2015) details are given on how public bodies must work together. They must consider what can be achieved alone and what must be achieved in collaboration with bodies. The five key principles include: 'long term, prevention, integration, collaboration and involvement.' The Local Air Quality Management Regime is going to be adapted in the following ways. Firstly, a more streamlined reporting system which will involve annual progress reports each year rather than updating and screening assessments

and progress reports. Furthermore, Local Authorities will not be required to complete a detailed assessment before declaring an AQMA if sufficient information is already available. Streamlining these procedures is thought to reduce the reporting burden making local authorities more effective (Welsh Government, 2016). This new document released for Wales has addressed several of the concerns relating to current Local Air Quality Management.

Cleaner Air for Scotland - The Road to a Healthier Future (CAFS), is an air quality strategy designed by the Scottish Government (2015). The strategy has been designed to act as a framework for the Government and other stakeholders to follow so that compliance with the Air Quality Objectives can be achieved in the shortest possible time. It considers the importance of reducing air pollution for the health of the population and also considers the wider benefits. To achieve improvements, six key objectives have been set across the following areas: '*transport, health, legislation and policy, place making, climate change and communication'* (Scottish Government, 2015). The strategy has outlined several new initiatives including National Modelling Framework, National Low Emission Framework, Adoption of World Health Organisation Guidelines for particulate matter and a proposed National Air Quality Awareness campaign. The strategy also sets key performance indicators which are going to be used to assess the progress and success of its implementation among the stakeholders and the government will produce an annual progress report. To achieve reductions in air pollution the strategy recognises this cannot be achieved by one government department. The strategy places responsibility on all citizens in Scotland to encourage change and various departments and local industry. For the transport sector in particular four methods have been recommended. These include, reducing the need for travel through spatial planning, increasing the uptake of low emission vehicles and active transport methods and finally improving engine technology. To ensure measurable change is made and progress can be measured, actions have been outlined with target dates for various departments and organisations (Scottish Government, 2015).

The reviews which have been completed in Scotland and Wales could lead to significant changes in the way in which air quality will be managed in future years.

Both initiatives are recently released therefore comprehensive reviews of the success of their implementation have not been completed to date. From reviewing the documents, it is evident that several of the deficiencies in the Local Qir Quality Management system have been considered when developing these new strategies. There is a particular emphasis on engagement and acknowledging that air pollution is a shared responsibility.

The government in Northern Ireland has produced a Programme for Government which outlines the main areas which they plan to improve while in office. Indicator 37 of the plan states; 'Reducing the Annual mean nitrogen dioxide concentration at monitored urban roadside locations.' (Northern Ireland Executive, 2016). This indicates that they are aware that nitrogen dioxide levels need to be reduced and that it will be considered when decision making in the following years. Currently in Northern Ireland, a review of the implementation of Local Air Quality Management has not been completed. This means it is the last of the devolved administrations not to have made changes to the procedure of managing air pollution. It is evident that air pollution levels need to be reduced to comply with the objectives, therefore a review with recommend actions is required.

2.5 Air Pollution Management in Other Countries

There are various different approaches used to manage air pollution in countries throughout the world. The methods used will be compared and contrasted with the current system in the United Kingdom.

All European countries are required to comply with the air quality objectives set in Directive 2008/50/EC. Countries are given the objectives and a date for which compliance is expected to be achieved. **Table 3** provides a comparison of the objectives set for European countries and those set in other countries for nitrogen dioxide and particulate matter. The table also states the recommended levels in the World Health Organisation Guidelines. These guidelines act as an international reference point for thresholds of pollutants which pose a risk to health. The guidelines are based on a review of scientific evidence however countries are not legally obligated to achieve the objectives (World Health Organisation,2016).

Table 3: Comparison of Air Pollution Guidance

Region	Pollutant			
	Nitrogen Dioxide (µg/m^{-3})		Particulate Matter (Pm10 µg/m^{-3})	
	1hr	Annual	24hr	Annual
WHO	200	40	50	20
Europe	200 (not to be exceeded more than 18 times per year)	40	50	40
USA	-	107	150	-
Hong Kong	200 (not to be exceeded more than 18 times per year)	40	100	50
China	200	40	50	40
India	-	40	100	60
South Africa	200	40	120	50
Australia	120	30	150	-

(Source: Wirth, 2012)

Table 3 illustrates that the guidance countries publish on human exposure varies. Different decisions have been made in regard to identifying an exposure level which is considered protective of health. The lack of a harmonised air quality standard indicates that there is a lack of agreement for what is considered a safe level of exposure.

2.5.1 Air Quality Management in European Countries

In the United Kingdom, the Local Air Quality Management (LAQM) regime is used to manage the levels of air pollution. There are various other systems used by other countries to control their air pollution levels. The systems are critically reviewed below to identify potential strategies to enhance the current system in the United Kingdom.

2.5.1.1 Ireland

In Ireland, the Environmental Protection Agency is designated as the competent authority. The requirements from the European Union are transposed into legislation via the Air Quality Standards Regulations. Air Quality is monitored at 31 locations across Ireland and currently there are no exceedances for nitrogen dioxide

(EPA, 2015). The number of monitoring stations in Ireland is low compared to the population number. This can be seen through a comparison of the number of monitoring sites per million people. Ireland have 6 monitoring sites per million people compared to Northern Ireland which has 11, Norway which has 10, Scotland has 17 and Wales 10 per million people (EPA, 2016). If an exceedance of the limit values is found the agency is required to produce an action plan within two years (EPA, 2016). The system in Ireland is similar to that in the United Kingdom however the requirements for reporting in Ireland are less than those required for the Local Air Quality Management system in the United Kingdom. The agency manages the monitoring and reporting compared to local authorities in the United Kingdom.

2.5.1.2 Germany

In Germany, air pollution from traffic is a challenge in the large cities. The competent authority is the German Federal Environment Agency (UBA). The requirements of EU directives have been transposed into two pieces of legislation including; Act on the Prevention of Harmful Effects on the environment caused by Air Pollution, Noise, Vibration and Similar Phenomena and secondly, Technical Instructions on Air Quality Control. This second piece of legislation gives power to German Authorities to control air pollution.

The German Authorities have recognised that for reductions to occur, action needs to be taken in several areas. Technological advances are required to reduce emissions however it is recognised that relying on this method alone will not meet the objectives. For long term change to occur, Germany has recognised the importance of spatial planning. Reducing urban sprawl, reducing travel distance and increasing the use of alternative transport.

To increase the likelihood of action plans being implemented, a thorough stakeholder consultation process is completed. Institutions, associations and bodies are involved included NGO's and businesses. In addition, the public are invited to comment and then a public meeting is held. The last public consultation for the Berlin Action plan received 130 public responses which indicates a high level of public engagement. The agency recognises the importance of stakeholder engagement in easing the implementation of the action plan and have found it increases mutual understanding.

The effectiveness of measures is evaluated through monitoring results and modelling. A report is then produced evaluating the success and to influence future practice. To encourage best practice and increase understanding, a training system for those involved in air pollution has been established in Germany. The system (Train for Clean Air) provides training for NGO's, decision makers, technical staff and media representatives (German Partnership for Sustainable Mobility, 2015).

In Germany, 70 cities have introduced Low Emission Zones (LEZ). In 25 of these LEZs cars entering the zones must display a sticker on their windscreen which indicates the engine efficiency and emissions of their vehicle. In seven of the cities, only vehicles with a green sticker (lowest emission levels) are permitted to enter. Drivers who disobey this law are fined and penalty points are added to their licence. LEZ are now common features in many European countries (Scottish Government, 2015). There are many aspects of the German system of air quality management which the UK could implement. A greater focus on spatial planning now would help to reduce the air pollution in the future. In addition, encouraging public engagement in air pollution in the UK may produce behaviour change.

2.5.2 Air Pollution Management in Non- European Countries

In the United States, air pollution legislation has been in force since 1955 (Kuklinska et al, 2015). Traffic pollution is a concern across America. In response to this, legislation was introduced to reduce emissions from vehicles. The Environmental Protection Agency and the California Air Resources Board both have emission standards. Each state can choose whether to follow the EPA standard or the stricter California standard (Kuklinska et al, 2015). It is difficult to determine the success of controlling emissions from vehicles. Recently within the UK, emissions scandals highlighted the flawed testing system of new vehicles (ICCT, 2014). In the United States, air pollution is under federal control and the policies created must be followed by the whole country. When compared with the EU, the standard is set by the European Commission however each country determines the most appropriate method of implementing. There is also differences in enforcement if the guidelines are not met. In the United States, the federal administration has the power to take control of the management. In the EU, if the country fails to notify the commission

that they will not meet the objectives, they can send warning letters and may initiate legal action (Kuklinska et al, 2015).

In New Zealand the capital city Auckland has identified traffic as the main source of air pollution. There has been an increasing urban sprawl in the city and with poor public transport links to these areas therefore an increase in private car ownership has resulted. It currently has one of the highest car ownership rates in the world. Regional councils are encouraged to complete 'AirShed Action Plans' for areas which to not comply with the standard for particulate. Furthermore, the councils may also complete plans for areas which do comply to prevent future exceedances. In contrast with the United Kingdom, total focus is on non- compliant areas. In the future a broader approach to air pollution management could be implemented to prevent potential 'hot spot' areas. In New Zealand, regional councils are required to monitor air pollution levels and have built an extensive continuous monitoring regime. They are required report any breaches of the air quality standards on a monthly basis until the standard is met. The Council declared one large 'airshed' for the metropolitan area of Auckland. Within the declared 'airshed' monitoring must be completed in the worst case scenario for levels, public exposure and length of exposure (Symons et al, 2007). This is similar to the UK where monitoring must take place in areas where the public are likely to be exposed.

In China, rapid growth in industry and urbanisation has led to an increase in air pollution in recent decades. High levels of air pollution have led to photochemical smogs in several Chinese cities. In response to the excessive levels, the government introduced several policies to reduce air pollution exposure. The country currently has Ambient Air Quality Standards which legally set objective levels for pollutants including $N0_2$, PM_{10}, $PM_{2.5}$, $S0_2$, CO and O_3. The government have also set out 10 key principles in their 'Action Plan on Prevention and Control of Air Pollution' such as establishing a monitoring and warning system, increasing the use of modern technology to reduce air pollution and regional management of air pollution. Before hosting the Beijing Olympics, a series of steps were taken to reduce the levels of air pollution. This included a scrappage scheme for 23,000 vehicles and increasing the amount of green space in the city. In addition, during the games a vehicle restriction

strategy was implemented which included restricting the number of vehicles on the road using odd and even registration numbers and a ban on 300,000 heavy polluting vehicles. Further longer lasting measures were also introduced including, improvement in fuel quality, increase in public transport promotion and an increase in alternative fuel vehicles. More recently the Beijing government has introduced a 'public transport priority strategy' and is limiting the number the total number of vehicles in Beijing (Zhang et al, 2016).

India have exceedances in various cities across the country due to traffic, industry and agriculture. Recently the government launched a series of measures in relation to air pollution including establishing a national monitoring network, ambient air quality standards and an air quality index. A 42-point action plan has been produced with practical points on how to reduce air pollution levels such as creating vehicle emission standards. The government have also included a public awareness and outreach programme which will be launched to increase public involvement in air pollution (Ministry of Environment, 2017).

2.6 Summary

Traffic related air pollution is a problem for many developed countries. Although there are different methods used in managing the problem, the same key principles are applied. The literature reviewed on Local Air Quality Management indicated that the current system effectively identifies problem areas however is insufficient at reducing the levels of air pollution. Reviews of the system have been completed in certain parts of England and Scotland but yet to be completed in Northern Ireland. Northern Ireland is in a unique situation as it is a devolved administration with different local government departments and different services within local authorities. Furthermore, Northern Ireland has a scattered land use and settlement pattern which maybe one of the reasons for the higher dependency on private cars compared to other parts of the United Kingdom. The transport system is unique with some areas not serviced by a rail link. A tailored review of the effectiveness of LAQM in Northern Ireland would be beneficial.

2.6.1 Research Gaps Identified

From completing a detailed review of the current available literature on Local Air Quality Management the following research gaps have been identified:

- Review of the effectiveness of LAQM have been completed in other parts of the United Kingdom. No review has focused on the implementation in Northern Ireland and its effectiveness of reducing air pollution levels.
- Lack of current research available on the effectiveness of communicating air pollution information

This chapter has outlined the legal requirements to monitor and assess air pollution levels. The main objective for monitoring air pollution is to understand what the public is being exposed to. **Chapter 3** focuses on the impact of traffic related air pollution on the public. This includes their awareness and perception of air pollution, the current evidence on the health impact of air pollution and the literature on exposure to air pollution from traffic.

Chapter 3- Air Pollution Exposure and the Impact on Health

3.1 Introduction

Chapter 1 stated the extent of traffic related air pollution from a worldwide, national and local scale. It is evident that air pollution is widespread, with pollutant levels exceeding the European Objectives and the more stringent guidelines set by the World Health Organisation. Chapter 2 introduced the legislation governing air pollution control and critically evaluated the current management system.

Chapter 3 provides an overview of exposure to traffic related air pollution and the current health effects identified in literature. The chapter is divided into three sections which focus on: exposure to traffic related air pollution, the health impact of exposure and the public's awareness and perception of air pollution.

The aim and objectives are stated at the beginning of the chapter. The objectives outline the focus of the chapter and demonstrate how the aim will be met. The chapter concludes with a summary of the key findings and highlights the current gaps in literature.

3.1.1 Aims and Objectives

The aim of the chapter is to;

Identify the health impact of exposure to traffic related air pollution and the public's awareness and perception of air pollution

The aim will be met through the completion of the following objectives;

- Identify and review the literature on exposure to traffic related air pollution indoors and outdoors
- Identify the factors within the built environment and natural environment which can impact on the levels of air pollution
- Create a comprehensive list of the health effects which have been associated with exposure to traffic related air pollution
- Identify from the research what is considered a 'safe' exposure level
- Evaluate if the current limit values for air pollution are protective of health
- Identify literature on the awareness of traffic as a source of air pollution

- Identify the literature available on public knowledge of the health effects of traffic related air pollution and local air quality management
- Evaluate the current techniques used to communicate air pollution information
- State the current gaps in literature in relation to exposure, health impact and awareness of air pollution

3.2 Exposure to Air Pollution

The majority of previous research focuses on outdoor air pollution at residential locations. This review considers whether this is adequate to fully understand exposure to traffic related air pollution. The spatial variability of air pollution is explored by identifying the natural and built environment factors which impact on the levels. This chapter provides a focused review of the current evidence on the monitoring of traffic related air pollution and identifies the current gaps in literature.

3.2.1 Search Strategy

To ensure a comprehensive search of available literature was completed a search strategy was devised. The search terms used to identify the literature are detailed below. Traffic related air pollution (TRAP) is a commonly used term throughout air pollution research. This research focuses specifically on nitrogen dioxide therefore all abbreviations were included in the search term.

Each of the terms were combined with one of the following expressions for air pollution;

'traffic related air pollution', 'air pollution from traffic', 'nitrogen dioxide', N02', 'NOx' and 'traffic'

AND

'Indoor/Outdoor Air Pollution', 'Indoor Outdoor Ratio', 'Exposure', 'time activity'

These search terms were used in several databases consisting of Science Direct, PudMed and Scopus. All searches were limited to articles published in English. The gaps in literature are stated throughout and highlighted at the end of the chapter.

The results of the literature search are presented in 4 main themes which are stated below;

- Theme 1 – Time activity pattern
- Theme 2 – Monitoring of traffic related air pollution
- Theme 3 – Indoor and Outdoor levels of traffic related air pollution
- Theme 4- Natural and Built Environment factors influencing air pollution levels

The literature for Theme 4 was identified through an additional search strategy which is stated in **Section 3.2.5**.

3.2.2 Time Activity Pattern

Exposure assessment has been defined as, '*the process of estimating or measuring magnitude, frequency and duration of exposure to an agent*' (Zartarian et al., 2007). Taking this definition into consideration, exposure to traffic related air pollution should include the measurement of air pollution levels and consider the length of time the person is exposed to the pollution. The assessment should take into consideration the source, pathway and any uncertainties. Human exposure is difficult to comprehensively estimate due to the number of relationships and interactions between the environment and individual factors (Steinle et al, 2013). Throughout this review the factors which impact on exposure will be identified.

3.2.2.1 Number of hours spent in microenvironments

There are various studies completed which have investigated the average number of hours people spend indoors and outdoors (Kornartit et al, 2010., Schembarri et al, 2013). The results vary but there is agreement that each day people spend the majority of their time indoors. One study found that on average over 80% of a person's time is spent indoors (Kornartit et al, 2010). Another study found participants spent at least 60% of time at home and overall 79% of time indoors (Schembarri et al, 2013). The World Health Organisation (2014) have stated that people spend up to 90% of their time indoors with an average of 70% at home or

office environment. These statistics indicate that the indoor environment should be an important consideration in exposure studies. There are many exposure studies (Tabaku et al, 2011; Villeneuve et al, 2012; Liu et al, 2012; Beelan et al, 2014) which have assigned exposure using average outdoor concentration levels however this assumes that indoor levels are equivalent to outdoor exposure. There is an emergence of studies which investigate exposure to air pollution in several micro environments (Regettli et al, 2015; de Kluizenaar et al 2017; Requia et al, 2017). People are not 'static' and therefore are exposed to air pollution in different locations. Research has started to investigate exposure which incorporates home, work and commute exposure (Refettli et al, 2015; de Kluizenaar et al 2017; Requia et al, 2017). Although the studies are investigating different locations there are still weaknesses within the research. The weaknesses include estimating exposure using modelling techniques and only considering the outdoor concentration at each of location. The consideration of indoor levels of air pollution is discussed in greater detail in **Section 3.2.4**.

The weather is a factor which can influence the number of hours spent indoors therefore research completed in warmer climates may find that a greater amount of time is spent outdoors. In agreement with this, a study found that a greater number of hours was spent indoors in the winter compared to the summer (Kornartit et al, 2010).

Traditionally human activity had been assessed using time activity diaries (Schembori et al, 2013; Steinle et al, 2015). The participant is asked to complete on a daily basis the amount of time spent in different micro environments. This method has some disadvantages as the accuracy of the information gathered depends on the willingness of the research participants. To overcome this, recent research has made use of technology to track research participants. Mobile phones which are GPS enabled have allowed researchers to identify the participants' movements within different microenvironments (Ouidir et al, 2015; Steinle et al, 2015). This has allowed for a more accurate representation of where time is spent. Furthermore, participants have also been tracked by using mobile phone data (Su et al, 2015_b; Dewulf et al, 2016). Both these methods represent ways to track human mobility and identify

exposure locations however concerns have been raised in regards to privacy issues when using these methods. Although more accurate data is gathered, consideration needs to be given to ethical issues when using mobile tracking devices and the impact which it may have on the response rate.

3.2.3 Measurement of Traffic Related Air Pollution

There is a mixture of pollutants emitted from vehicles into the atmosphere. There are studies completed which have focused only on the impact of particulate matter (Chithra and Nagendra, 2012; Karottki et al, 2014). In addition, there is also research which is has focused on nitrogen dioxide (Karakatsani et al, 2010; Skene et al, 2010; Liu et al, 2012; Gallagher et al, 2013; Beelan et al, 2013; Schembori et al, 2013). Nitrogen Dioxide is considered a marker for traffic related air pollution therefore is often measured within research. It has been identified as a suitable representation of traffic related air pollution by the Health Effects Institute (HEI, 2010). People however, are exposed to a range of pollutants therefore research should consider the cumulative impact and exposure to air pollution from traffic. There are few studies which have measured the levels of several pollutants (McAdam et al, 2011; Tabaku et al, 2011; Bogard et al, 2012). These studies also only consider the outdoor levels of a range of pollutants. However, another drawback is that measuring the impact of a range of pollutants indoors may cause disturbance to the research participants due to the extra equipment required.

There are various different methods used to assess air pollution levels. These can be broken down into three broad categories; modelling, monitoring and existing data sets. One method of monitoring air pollution which is often used is centrally located automatic monitoring stations. Within this review there have been several studies which have used this technique (Brunkreef et al, 2007; Sarnet et al,2010; Karottkia et al, 2014). These stations are useful as they can monitor a wide range of pollutants and have a high level of accuracy. However, they do not take into consideration the spatial variation of air pollution (Steinle et al, 2013). If they are not well situated they may poorly represent the population's exposure. Previous research has also used proximity to the road to investigate the impact of exposure to traffic related air pollution (Jerrett et al, 2010; Hannam et al 2013). This method inaccurately assumes

that all residents within a certain distance from the road are exposed to an unacceptable level of air pollution. The level of traffic related air pollution has also been associated with the traffic density in an area (Su et al, 2015). Traffic density is widely used in air pollution research. It can be used as a proxy and in land use regression studies. However, this method can erroneously assume that residents living on a road with a certain number of cars are exposed to high levels of air pollution. Measuring residential proximity to the road and the number of vehicles rather than air pollution levels does not consider the impact of factors which affect dispersion. The levels of air pollution vary due to natural and built environment factors which are discussed in greater detail in **Section 3.7**.

Personal monitoring is emerging as a new method of identifying exposure as it can provide a snapshot of detailed information on the level of air pollution a person is exposed to in daily life. Personal monitoring is most successful when suitable monitors are used. Monitors are required to accurately measure levels of air pollution yet also be low cost so a representative sample can be simultaneously monitored. The monitors however, need to be wearable and obtrusive to encourage research participants to partake. One of the main considerations in choosing a personal monitor is to minimise the inconvenience to the research participant. It would have to small and light to not interfere with their normal routine. Furthermore, for some research participants, discretion would also be a factor in whether they would agree to participate. All these factors need to be considered when choosing a personal monitor (Steinle et al, 2015).

There are various methods and locations which current literature uses to identify exposure to traffic related air pollution. Personal monitoring is a method which recent publications have focused on. The use of existing data sets or estimating a cities exposure using one measurement does not consider the variability of air pollution or the movement of people therefore inaccurately estimates exposure.

3.2.4 Indoor and Outdoor levels of Traffic Related Air Pollution

Building regulations have led to new homes being constructed with greater air tightness. The impact which this had on indoor air quality and occupant health has not been considered within current literature (Awbi, 2015). Nitrogen dioxide levels have been measured in several commercial buildings. The results indicated that the older buildings had lower levels of nitrogen dioxide. The lower levels were attributed to a variety of chemical reactions which are intensified because of the high density of people in the offices, the large surface area and the humidity (Challoner and Gill, 2014). In recently constructed buildings, the low permeability of the building envelope has meant that air pollutants produced within the buildings begin to accumulate and lead to exposure to higher levels. However, the lower permeability can also protect against the entry of outdoor pollution (Milner et al, 2015). This indicates that recently constructed homes may provide greater protection from traffic related air pollution.

Section 3.3 reviews the current literature on the health effects of air pollution. The majority of studies in the review either used existing data sets, central automatic monitoring stations or monitored ambient air pollution levels to identify exposure. This classification of exposure may over or under estimate the levels which individuals are exposed to (Sajani et al, 2016). The Health Effects Institute (2015) investigated exposure to $PM_{2.5}$ and found that outdoor levels did not fully represent personal exposure to the pollutant. This is further confirmed by a study completed in the United Kingdom which concluded that measuring both indoor and outdoor nitrogen dioxide levels was more representative of personal exposure rather than relying solely on outdoor levels (Kornartit et al, 2010). Studies which have measured or modelled both indoor and outdoor levels are in agreement that measuring both levels is a more reliable indicator of personal exposure (Kornartit et al, 2010; Stroh et al,2012; Demirel et al, 2014; HEI, 2015). When both indoor and outdoor levels have been measured, indoor levels have been found to link more closely to personal levels than outdoor levels (Valero et al, 2009., Demirel et al, 2014).

Outdoor levels of nitrogen dioxide and particulate matter were found to impact on indoor levels in several studies (Chen et al, 2012; Meadow et al, 2014; Fung et al,

2014; Meier et al, 2015). Although a link was found there was a large amount of variability in the levels which indicates the factors within the home and the building fabric could influence indoor levels (Meier et al, 2015).

3.2.4.1 Factors affecting indoor air quality

There have been several factors identified as important to consider when measuring indoor levels. Cooking was found to contribute to the levels of nitrogen dioxide. Higher levels were found when residents were using gas stoves and when there was a prolonged period of cooking (Kornartit et al, 2010; Schembari et al, 2013; Meier et al, 2015). The levels of nitrogen dioxide within a house with a gas cooker were found to be two times higher than those using an electric cooker (Kornartit et al, 2010; Dedele and Miskinyte, 2016). Window opening has also been found to be influential on the indoor levels of pollutants emitted from vehicles (Meier et al, 2015). One study recommended that indoor monitoring is completed in rooms which are unoccupied in the property to reduce the influence of other factors (Meier et al, 2015). Furthermore, research participants who smoke indoors was another factor which contributed to indoor levels of nitrogen dioxide (Beko et al, 2013; Schembari et al, 2013; Gu et al, 2015; Meier et al, 2015). All of these factors need to be considered when selecting research participants.

Ventilation systems and air conditioning have also been identified as impacting on the indoor levels of air pollution. Levels of nitrogen dioxide were found to be lower in naturally ventilated buildings compared to those which had mechanical ventilation (Challoner and Gill, 2014). The same study (Challoner and Gill, 2014) also found that daytime levels of nitrogen dioxide were lower than night time levels. Furthermore, high levels were seen during the evening due to the reduced ventilation in the buildings (Challoner and Gill, 2014). Bedrooms were found to be the rooms which had the highest level of ventilation as residents are more likely to regularly open windows. This indicates that the bedroom is the room where the influence of outdoor air is most likely to affect indoor levels. It is also the rooms with few other sources of nitrogen dioxide (Santina and Itarda, 2010; Fabi et al. 2012; Dedele and Miskinyte, 2016). The factors mentioned above which impact on indoor air quality

would need to be taken into consideration when designing future monitoring programs to ensure accuracy when comparing results.

3.2.4.2 Measured levels of Indoor and Outdoor Air Quality

The levels of indoor and outdoor levels vary within published literature, as well as evidence on the relationship between indoor and outdoor air pollution. A number of studies have found that indoor levels of air pollution are higher than outdoor levels of air pollution (Senitkova,2000; Algar et al, 2004; Lai et al, 2006; Challoner and Gill, 2014). This evidence in conjunction with the knowledge that people spend more time indoors indicates that greater focus needs to be given to indoor air quality. However, the evidence that indoor levels are higher than outdoor levels should be viewed with caution as some measurements were taken in kitchens which have other sources of nitrogen dioxide such as cookers and boilers. In addition, the research participants were not selected on the basis that they live in an area known to have high levels of outdoor air pollution. Research which specifically focuses on the impact of outdoor air on air quality is required.

3.2.4.3 Methods used to measure levels

There have been several studies completed which have predicted exposure to nitrogen dioxide by modelling the levels (Stroh et al,2012; Jerrett et al, 2013; Regettli et al, 2015; Buteau et al, 2017; Su et al, 2015$_{b;}$ Shekarrizfard et al, 2016; Tong et al, 2016; Dimitroulopoulou et al, 2017). The most common method is land use regression models (Jerrett et al, 2013; Su et al, 2015$_{b;}$ Shekarrizfard at al, 2016). A discussion of the common modelling techniques used in air pollution research is completed in **Chapter 4**. Buteau et al (2017) compared the results of four different models for their performance in predicting the levels of nitrogen dioxide. Significant differences were found between the levels using the different models. The study concluded by not recommending any models but advising researchers that if using models, a combination of models should be used. This indicates that models may not always be a reliable indicator of air pollution levels. In addition, other studies have used existing data sets or central monitoring stations (Ozkaynak et al, 2013; Rodríguez et al, 2016). This method erroneously assumes that people have the same level of exposure all day. There has been a limited number of studies which have

measured the levels of both indoor and outdoor levels at each property (Senitkova,2000., Lai et al, 2006., Algar et al, 2004., Kornartit,2010., Kotzias et al, 2011., Jovanovic et al, 2013., Schembarri et al, 2013; Rivas et al, 2014., Challoner and Gill, 2014). These studies have measured levels at various locations such as schools (Kotzias et al, 2011., Jovanovic et al, 2013., Rivas et al, 2014), offices (Challoner and Gill, 2014., Wang et al, 2015), and home (Lai et al, 2006; Kornartit, 2010). The studies have not been focused on locations which are known to have high levels of air pollution such as air quality management areas.

Several studies also measured personal exposure to nitrogen dioxide alongside the indoor and outdoor levels. The most common method was the use of passive badges (Kornartit et al, 2010; Schembarri et al, 2013). A review of the methods used to measure nitrogen dioxide is completed in **Chapter 4.** High correlation was found between the personal level of nitrogen dioxide and the indoor level (Kornartit et al, 2010; Schembarri et al, 2013). This indicates that as indoor levels of air pollution increase, personal exposure also increases. In addition, a study conducted by Ouidir et al (2015) found that personal levels of nitrogen dioxide did not correlate with the modelled outdoor level at their home address. This suggests that research estimating outdoor air pollution levels using a model does not accurately predict human exposure. Kornartit et al (2010) found that personal exposure to nitrogen dioxide was higher in the summer rather winter. This may be due to an increased amount of time spent outdoors.

Previous research has focused on vulnerable groups and their exposure to air pollution including indoor, outdoor and personal exposure. This includes pregnant women (Valero et al, 2009; Wu et al, 2011; Minguillón et all, 2012; Schembari et al, 2013; Ouidir et al, 2015) and children (Roosbroeck, 2006; Demirel et al, 2014). To date no previous research has focused on people who are vulnerable due to their residential location. For example, within the United Kingdom people living in air quality management areas would be most at risk of exposure to high levels of air pollution.

There is currently no European legislation on acceptable exposure levels for indoor air pollution from ambient sources (Challoner and Gill, 2013). Current guidance

focuses on emissions from indoor sources such as heating and cooking appliances. Due to the lack of available standard, it is difficult to compare indoor levels or identify what an acceptable level is.

Table 4 summarises the current literature on the indoor and outdoor levels of nitrogen dioxide. There is variation in the levels found and the differences between indoor and outdoor air pollution. There are areas where indoor levels are higher than outdoor and areas where the opposite is found.

Table 4: Indoor and Outdoor levels of Nitrogen Dioxide in Current Literature

Author	**Location**	**Nitrogen Dioxide Levels µg/m^3**		**Method**
		Indoor	**Outdoor**	
Valero et al, 2009	Spain	42	36	48hr Monitoring Period Passive samplers Median Levels
Dedele and Miskinyte, 2016	Lithuania	19.3	20.3	Passive Samplers Average Levels
Kornartit et al, 2010	Hertfordshire	15	25	7 Day Monitoring Period Diffusion Tubes Average Levels
Schembari et al, 2013	Barcelona	60.6	51.6	7 Day Monitoring Period Passive Samplers Average Levels
Valero et al, 2009	Valencia	36	42	48hr Monitoring Period Passive Samplers Average Levels
Challoner and Gill, 2014	Dublin	76	150	Chemiluminescence Monitor Average Levels
Jovanovic et al, 2014	Serbia	7.4	9.14	10 Day Monitoring Period Passive Samplers Average Levels

Rivas et al, 2014	Barcelona	30	47	4 Day Monitoring Period Passive Samplers Average Levels
Johnson et al, 2010	Detroit	28	36	7 Day Monitoring Period Passive Sampler Average Levels

3.2.5 Factors Impacting on Nitrogen Dioxide levels

Emissions from vehicles are a unique form of air pollution as they are emitted at ground level and often where there is a large population (Su et al, 2015). From the literature reviewed there were several factors identified which were found to either increase or decrease the levels of nitrogen dioxide. The factors were both in the natural environment and the built environment.

Nitrogen dioxide has ambient, diurnal and seasonal characteristics. Diurnal trends in nitrogen dioxide demonstrate the levels are influenced by various factors. For example, traffic levels, flow and meteorological conditions impact on the variation of levels. Variation is also influenced by the time of day. In the evening traffic levels are low but dispersion is less efficient due to a lower wind speed and a more stable atmosphere (DEFRA, 2013). Higher levels are often found in congested locations where there is slow moving traffic compared motorways where vehicles are travelling at a higher speed. Seasonal impact is another consideration in air pollution research. Weather conditions in both summer and winter have been found to impact on the levels of nitrogen dioxide. In winter there is a trend of lower dispersion rates leading to peaks in nitrogen dioxide levels. Lower levels in summer can be attributed to the formation on ozone (DEFRA, 2013).

To identify current literature on the factors which influence the levels traffic related air pollution a search was completed in several databases including Science Direct and Scopus. The following search terms were used;

Air Pollution Levels

'traffic', 'traffic related air pollution', 'Nitrogen Dioxide', 'NO2', NOx

AND

Built Environment

'built environment', 'street canyon', 'barriers', 'distance'

Natural Environment

'natural environment', 'trees', 'vegetation', 'weather', 'weather conditions', 'meteorology' 'wind speed', 'wind direction', 'rain', 'temperature', 'season'

3.2.5.1 Natural Environment

3.2.5.1.1 Meteorological Impact

Temperature and season were both found to impact upon the levels of nitrogen dioxide (Schembari.,2013; Fantozzi et al, 2015; Rodríguez et al, 2016). The temperature can affect the removal and formation rate of certain pollutants (Patton et al, 2014). In general, the majority of literature reviewed found that as the temperature increases the level of nitrogen dioxide decreases. The reason for this decrease has been attributed to the formation of ozone which occurs due to a reaction between nitrogen oxide and sunlight. This also indicates that as the level of nitrogen dioxide decreases in warmer temperatures, the level of ozone increases (Sayegh et al, 2016). There is conflicting evidence which states that warm weather can cause an increase in air pollution levels (Vanos et al, 2013; Ramsey et al, 2015; Papanastasiou et al, 2015). Heat waves were found to cause an increase in exceedances. This conflict in evidence may suggest that extreme warm weather causes an increase in levels compared to average summer temperatures (Papanastasiou et al, 2015). The impact of temperature on different pollutants should be further investigated.

The level of air pollution can increase during the winter due to temperature inversions. This occurs when a layer of atmosphere near the earth's surface is at a lower temperature than the air above it. This causes a smog due to the air pollution being trapped at ground level (Largeron and Staquet, 2016). The majority of evidence

on the impact which seasonal fluctuations can have on air pollution levels is in agreement that levels are higher in the winter compared to the summer (Unal et al, 2011., Chen et al, 2013., Russo et al,2014., Li et al, 2014., Patton et al, 2014., Ghafghazi et al, 2015., Dedele and Miskinyte, 2016). The majority of research on temperature and air pollution levels is completed in climates which have extreme weather conditions such as China in winter (Li et al, 2017) and summer (Lin et al, 2017). Further research should consider seasonal variation in countries with more moderate temperature changes.

Wind speed and direction are influential on the dispersion of traffic related air pollution. An increase in wind speed leads to a decrease in pollutants (Patton et al, 2014., Zhang et al, 2015., Sayegh et al, 2016). The impact of meteorology such as wind speed and temperature is often investigated in street canyons (Blackman et al, 2015., Zhang et al, 2015). The effect of the weather conditions is heightened within a street canyon due to the limit on dispersion. Wind tunnels are also a method which are commonly used when investigating the impact of weather on air pollution levels. Further research is required in real world conditions.

Rainfall has also been found to impact on the levels of air pollution. Several studies have identified rain to cause a reduction in levels (Aurangojeb et al, 2011., Nowak et al, 2013., Ramsey et al, 2014) and therefore reduce the number of days where an exceedance is identified (Ramsey et al, 2014). The reduction has been attributed to the rain washing the deposited particles from the leaves of trees therefore allowing the stomata to absorb air pollution (Nowak et al, 2013).

3.2.5.1.2 Vegetation

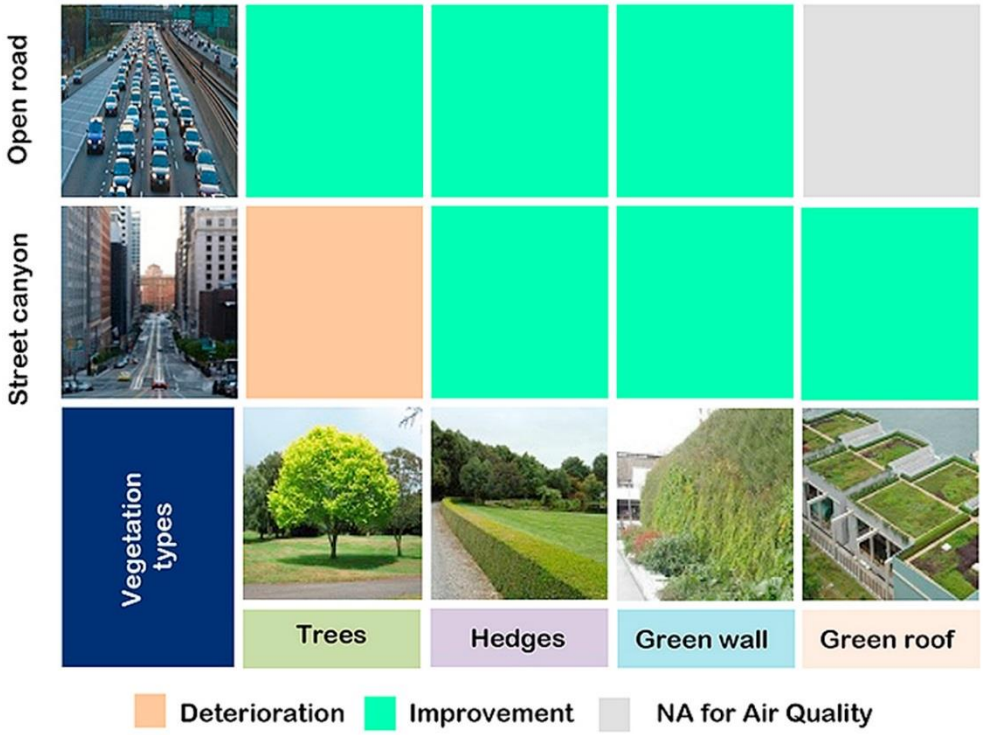
Trees and vegetation can impact on the levels of air pollution in an area. Current literature has found that it can increase or decrease levels depending on the type of tree. The size of the tree, leaf density and spacing of trees all impact of the effectiveness of trees in reducing air pollution (Gallagher et al, 2015). Furthermore, the impact which trees can have also depends on the street layout and geometry (Gallagher et al, 2015). There are various methods by which trees can create a reduction in air pollution levels. One method is by the stomata on the leaves of the tree absorbing the pollutant (Yli-Pelkonen et al, 2017). In addition, trees and hedges

have been found to act as a barrier between the source of air pollution (traffic) and the receptor (Brantley et al, 2014). Abhijith et al (2017) conducted a review of the current literature on the effectiveness of different types of vegetation in different locations including street canyons and open roads. In a street canyon trees were found to increase the levels of air pollution. The reason for the increase is the impact which trees can have on the wind speed in a street canyon. The trees lower the wind speed therefore reducing the air exchange rate, leading to a build-up of pollutants in the street (Buccolieri et al, 2015., Abhjith et al, 2017). This is in contrast to open roads were both trees and low level vegetation were found to reduce air pollution levels by acting as a barrier. Trees planted a greater distance from the pollution source were found to be more effective at reducing the level of air pollution (Vos et al, 2013). The findings of the review are summarised in **Figure 3**.

Although there have been several studies which have identified a reduction in air pollution from trees, they have also been published research which has found trees to increase the levels (Vos et al, 2013., Jin et al, 2014., Gromke and Blocken, 2015., Janhall, 2015). Trees with a large canopy have been found to trap pollutants and therefore reduce their dispersion rate (Vos et al, 2013., Jin et al,2014., Gromke and Blocken et al, 2015). This may indicate that the ability of the stomata to filter pollutants is lower than the level of pollutants which the canopy traps.

Hedges are smaller in size and are positioned at ground level compared to trees. They usually have a higher leaf density which increases their ability to reduce air pollution levels. The evidence in relation to the reduction properties of hedges is mixed. There is less available evidence compared to the amount of literature on trees. The presence of hedges reducing air pollution levels has been identified in several studies (Li et al, 2016., Gromke et al, 2016). A study which modelled the impact of hedges on $PM_{2.5}$ found there was no impact on the levels (Vos et al, 2013).

Figure 3: Impact of Vegetation on Air Pollution Levels



(Source: Abhijith et al, 2017).

The effectiveness of vegetation was found to be impacted by temperature and climate. Current literature has suggested that trees were more effective at removing pollutants in countries with a warmer climate such as China and Italy (Chen et al, 2015). In cooler regions such as Finland, trees were found to be less effective (Grundstorm and Pleijel, 2014).

For aesthetic reasons and to contribute towards sustainable development many cities have introduced green walls or green roofs. Green walls have been recommended in literature to reduce air pollution but there is little available evidence on their effectiveness. Jayasooriyal et al (2016) found that a green wall led to a slight reduction in air pollution levels however was not found to be as effective as trees. Green roofs were also found to have a lower impact due to their distance from the road and therefore the emission source (Speak et al, 2012).

The majority of research investigating the impact of vegetation has been completed by modelling the impact or through the use of wind tunnels (Buccolieri et al, 2015., Gromke and Ruck,2012., Li et al, 2013). Few studies have measured the impact (Jin et al, 2014., Hofman and Samsun, 2014., Hofman et al, 2016). Measuring the impact

of trees on air pollution levels in an area is difficult. Trees take a long period of time for their height and foliage to mature therefore limiting the ability to accurately compare levels from pre and post planting (Abhijith et al, 2017). This may be the reason for the greater number of studies which use modelling and wind tunnels. Abhijith et al (2017) acknowledges that with modelling there is 'a level of uncertainty' therefore further measurement studies are required.

The impact which vegetation can have on the levels of traffic related air pollution is a complex issue. In summary, vegetation can have either have a positive or negative effect on the levels of traffic related air pollution depending on various factors. Taking into consideration the above literature, the following factors would need to be considered in the design of future research; number of trees, tree height, tree width, type of tree and size of canopy.

3.2.5.2 Built Environment

In addition to the natural environment, there are also factors within the built environment that determine the level of traffic related air pollution in an area. Every town and city is unique due to its combination of natural and built environment factors. Each of the factors are discussed along with the current available evidence.

3.2.5.2.1 Distance

Each monitoring location is unique due to its combination of built environment factors. One factor which has been included within the majority of monitoring strategies reviewed is the distance of the property from the road. Proximity to the road and therefore the source of pollution has been found to be influential on the level of exposure (Wang et al, 2014., Sajani et al, 2016). Levels of traffic related air pollution were found to decrease to background levels within 500m (Su et al,2015). This is in agreement the Health Effects Institute (2010) who have quantified exposure zones as 300 metres from a major road or 500 metres from a motorway. A study conducted by Patton et al (2014) found that the pollutant level was significantly reduced after a distance of 200 metres from the source.

3.2.5.2.2 Street Canyons

Street canyons are often used to investigate the levels of traffic related air pollution. A street canyon has tall buildings on each side of the road. The buildings hinder the

recirculation of air pollutants and impact on dispersion rates (Sayegh et al, 2016). One study identified an open road with a traffic volume 10 times greater than a nearby street canyon but had lower levels of air pollution (Rakowska et al, 2014). This indicates that street canyons are important locations for consideration even at lower traffic volumes.

Various factors have been identified within literature which impact on the levels within street canyons. These are the height and width of buildings, roof shapes, obstacles within street canyons and the gaps between buildings (Fu et al, 2017). Higher buildings hinder the exchange of air causing increased levels within the street canyon. Research has found that the greatest impact on levels was when buildings were over 40 metres as air pollution levels were found to increase by over 50% (Fu et al, 2017). Within a street canyon, as the street width increases, the level of air pollution is found to be lower. A two-time increase in road width was found to reduce levels by up to 90%. The increase in width allows for greater ventilation (Fu et al, 2017).

In literature, there are two common methods of assessing the impact of street canyons including the use of modelling (Chang, 2006., McNabola et al, 2009., Solazzo et al, 2008., Gromke and Blocken, 2015) or field measurements (Zhang et al, 2012., Rakowska et al, 2014., Karra et al, 2017). It was noted by Wang et al (2016) that models are useful for predicting the average air pollution levels but fail to identify the range of levels within a street canyon.

3.2.5.2.3 Barriers

The impact of barriers has also been investigated in current literature. Noise barriers are primarily placed to reduce the noise level from busy motorways however research has demonstrated they may also be effective in reducing air pollution levels. A study completed in America in real world conditions found that the noise barrier reduced air pollution levels by at least 15% with reductions of up to 50% seen at different times of the day (Bowker et al, 2007., Baldauf et al, 2008). The reduction of air pollution has been associated with barrier height. The higher the barrier the greater the reduction of pollutants (Hagler et al, 2011., Steffans et al, 2014). Warnings have also been made in literature that barriers may reduce levels in one

area but increase levels by distributing the pollutants further downwind (Ning et al, 2010). Consideration needs to be given to wind direction when monitoring the impact of barriers. Noise barriers are common on large motorways however low barrier walls are more frequently seen in urban areas. The impact of low barrier walls has been investigated in street canyons. In Dublin a low barrier placed on the edge of the footpath was found to increase pollutant dispersion therefore reducing the levels of air pollution (McNabola et al, 2008). Factors such as street geometry, wind speed and direction, vehicle turbulence and the configuration of the barrier (height, width, distance from the road) were found to impact on the effectiveness of reducing air pollution levels (Gallagher et al, 2015).

Further factors which influence on air pollution levels not mentioned above include road width, road gradient, speed limit and vehicle type (for example: age of vehicle and the number of HGVs) (Sayegh et al, 2016). It is evident that there are numerous factors which can impact on the levels of air pollution in a location. Consideration of these factors during the planning stage of construction projects could significantly reduce human exposure to air pollution. Wen et al (2017) have suggested that the breathability of cities needs to considered during the design stage, taking into consideration how different factors interact to influence air pollution levels.

Taking into consideration the spatial and temporal variability and all the influencing factors mentioned above, it is difficult to accurately estimate the level of air pollution. People are constantly moving during the day to different locations therefore individual exposure is unique. In addition, the research also indicates that the findings of air pollution research may be unique to the study location. The synergistic effect of natural and built environment factors result in low transferability of results to different locations.

3.2.6 Exposure to Traffic Related Air Pollution Summary

From the literature reviewed there are several key findings;

- People spend on average 90% of their time indoors therefore it is an important exposure location

- Distance from the road, presence of barriers and street canyons impact on exposure to traffic related air pollution
- Meteorology and vegetation have varying impacts on air pollutants emitted from traffic
- There is a high variability in air pollution levels as each location has unique built and natural environment features therefore results are often not transferable.

After reviewing the current evidence on exposure to traffic related air pollution there were several gaps in literature identified.

- Monitoring of traffic related air pollution – there is a still a large proportion of current research completed using models or estimates of air pollution levels.
- Indoor and Outdoor monitoring – the majority of previous research relies on outdoor measuring.
- Previous research on indoor, outdoor and personal exposure to air pollution has primarily focused on vulnerable groups such as pregnant women and children. Research needs to consider those who are vulnerable due to their residential location.
- In relation to the built environment and natural factors- the majority of previous research focuses on one aspect. Research needs to consider the cumulative impact of these factors.

This section has critically reviewed the current evidence on exposure to traffic related air pollution and the factors which can affect the levels of air pollution. **Section 3.3** reviews the evidence on the health impact of exposure.

3.3 Health Impact of Exposure to Air Pollution

This section critically evaluates the health impact of exposure to traffic related air pollution and identifies at what level health effects are observed. It is estimated that 40,000 deaths each year in United Kingdom are attributable to air pollution (Royal

College of Physicians, 2016). The Royal College of Physicians (2016) report does not state exactly how this figure is calculated but states that it should be considered as a 'statistical construct' indicating the potential impact of air pollution. This indicates that the result should be viewed with some caution.

Air pollution is now considered a major public health challenge due to the current available evidence on the health impact of exposure. This section reviews the current literature on the health impact of exposure to traffic related air pollution. There is currently a vast amount of research completed on the health effects of air pollution and this section aims to provide an overview of the evidence specifically in relation to the main pollutants emitted from traffic including nitrogen dioxide and particulate matter. Furthermore, the cumulative impact of exposure to a mixture of pollutants is included. Clarity is provided on the current available evidence.

The evidence from government reports and other agencies such as the World Health Organisation is summarised in **Section 3.3.2** and then the published literature is reviewed. The section concludes with a summary of the key findings and highlights the current gaps in literature in relation to health.

3.3.1 Current Reports on the Health Impact of Air Pollution

There have been several reports produced by government departments or other agencies in recent years which have summarised the impact of air pollution in the United Kingdom. The health effects that these reports have identified and the current statistics about the impact of air pollution are summarised throughout this section.

The Committee on the Medical Effects of Air Pollution (COMEAP) have made several statements on the impact of nitrogen dioxide and particulate matter. In relation to nitrogen dioxide they state that on 'the balance of probability' nitrogen dioxide is responsible for some of the health effects found in epidemiological research. As people are exposed to a mixture of pollutants, particularly in urban environments, it is difficult to determine the individual impact of nitrogen dioxide on health (COMEAP, 2015_a). A further statement was made in relation to the impact of particulate matter. It was stated that the adverse health effects identified in research from exposure to

particulate matter are 'at least in part causal' (COMEAP, 2015$_b$). This indicates that both nitrogen dioxide and particulate matter are linked to health effects but currently stronger evidence is available on the impact of particulate matter.

WHO (2016) has described air pollution as the biggest environmental risk to health. The Royal College of Physicians (2016) and WHO agree that air pollution affects people across their whole life from the womb to the elderly. It affects all regions, all settings, all socioeconomic groups and age groups.

3.3.1.1. Respiratory Illnesses

The Royal College of Physicians (2016) report stated that long term exposure to air pollution during childhood, can affect lung function. As children's lungs are still developing exposure can supress the process. The report states that children living in high pollution areas are four times more likely to have reduced lung function as adults (RCP, 2016). These findings agree with the World Health Organisations review of the medical effects of air pollution (2013) which also found an impact on lung function. Furthermore, consistent links between exposure and the exacerbation of asthma symptoms have been found (HEI, 2010).

3.3.1.2. Cardiovascular Illnesses

Strong links between exposure to ambient air pollution and cardiovascular illness have been found (RCP, 2016., WHO,2013., HEI,2010). Literature states that both short- term and long- term exposure can contribute to the development of cardiovascular disease in adults. Furthermore, exposure has been found to exacerbate symptoms of those with existing cardiovascular problems, increase hospital admissions and deaths to due to cardiovascular conditions. The strongest association was with particulate matter (RCP, 2016). HEI (2010) have stated that although there is strong evidence linking air pollution and cardiovascular disease the evidence is 'suggestive but sufficient' to confirm a causal link.

3.3.1.3. Cancer

The strongest evidence in relation to air pollution and cancer focuses on lung cancer. The World Health Organisation International Agency for Research on Cancer (2016) have classified ambient air pollution as carcinogenic to humans. The strongest association was found with cancer to the lung and bladder. Agreement on the impact

of ambient air pollution on the development of lung cancer was found in several of the reports (RCP, 2016., WHO,2016., HEI,2010).

3.3.1.4. Mortality

The majority of the reports within this review consider the impact of air pollution on mortality. HEI (2010) have stated that the link between exposure to ambient air pollution and all- cause mortality is 'suggestive but not sufficient.' A previous report found that as NO2 levels increased there was also an increase in all -cause mortality (WHO, 2013).

3.3.1.5. Other Illnesses

In addition to the health conditions mentioned above the reports have identified several other conditions which have been linked to exposure to ambient air pollution. There is a growing evidence base in relation to the following illnesses and air pollution; diabetes, cognitive effects (RCP, 2016), increase in hospital admissions (WHO, 2013) and adverse birth outcomes (WHO, 2013).

The reports produced by the Health Effects Institute, the World Health Organisation and the United States Environmental Protection Agency provide a comprehensive overview of the current available literature on the health impact of traffic related air pollution. It is evident that exposure to nitrogen dioxide and particulate matter results in health effects with the strongest evidence of respiratory illnesses. The reports include literature up to the year 2010 therefore a review incorporating the most recent research is required.

From the published government and agency literature the following health effects from exposure to traffic related air pollution have been identified;

- Respiratory illnesses including asthma and reduced lung function
- Cardiovascular illnesses
- Pre-natal exposure associated with premature birth and low birth weight
- Cancer- with particular focus on lung cancer
- Increased hospital admissions

The health effects found from reviewing these publications are used in developing the search strategy for the critical literature review in **Section 3.3.2**.

3.3.2 Critical Review of Current Literature on the Health Impact of Air Pollution

In preparation for conducting the critical literature review, a search strategy was devised to ensure the most effective and comprehensive method of searching. The search terms used are detailed below. All the health search terms were combined with any of the following terms for air pollution:

Air Pollution', 'Traffic Related Air Pollution', 'Outdoor Air Pollution', 'Ambient Air Pollution', 'Nitrogen Dioxide', 'NO2', 'Nitrogen Oxides', 'Particulate Matter', 'PM', 'Diesel', 'Traffic'

The search terms used for health conditions were identified using information from previous published reports. The results from the following reports were included;

- Health Effects Institute (2010): Review of the health impact of traffic related air pollution
- World Health Organisation (2013): Review of the medical effects of air pollution
- Royal College of Physicians (2016): Every breath report

The following terms were used;

- **Respiratory Illnesses**

  Search terms used;

  'Asthma', 'respiratory illnesses', 'respiratory health', 'respiratory inflammation', 'lung cancer', 'lung disease'

- **Cardiovascular**

  Search terms used;

  'cardiovascular illnesses', 'cardiovascular health', 'heart attack', 'hypertension', 'heart'

- **Pregnancy**

  Search terms used;

'birth defect', 'birth outcome', 'birth weight', 'pregnancy', 'foetus' , 'pre-natal', 'pre-term birth'

- **Other**

  Search terms used;

  'hospital admissions', 'illnesses', 'health', 'health impact', 'health effects', 'cancer', 'tumours'

The databases used included Scopus, Science Direct and PubMed. The search was limited to publications in English. Furthermore, due to the comprehensive nature of the reports in **Section 3.2.1** and due to the amount of research on the health impact of air pollution, it was decided to limit the results publications post 2010. The literature also solely focused on traffic related air pollution therefore any publications which included other sources were excluded from the review.

The results of the literature review are presented in 3 main sections including respiratory illnesses, cardiovascular illnesses and additional health concerns. The current gaps in literature will be highlighted throughout and stated at the end of the chapter.

3.3.2.1 Respiratory Illnesses

There is a vast amount of research completed on the effect of air pollution on respiratory health, with particular focus on asthma.

3.3.2.1.1 Asthma

Asthma is defined by the Health Effects Institute (HEI, 2010) as, 'an inflammatory disease of the lung airways characterised by episodic obstruction of the airways, which can lead to chronic obstructive lung disease.' In the United Kingdom there are currently 5.4 million people with asthma, which is more than all other lung conditions combined. This equates to around 12% of the population (British Lung Foundation, 2017). The link between exposure to increasing levels of traffic related air pollution and asthma is discussed below.

There have been various reviews completed on the impact of air pollution on the development of asthma and the worsening of asthma symptoms (Guarnieri and

Balmes, 2010., Khreis et al, 2017., Kim et al, 2013). These reviews have been comprehensive but have failed to focus solely on traffic related air pollution as a source (Anderson et al, 2013., Favarato et al, 2014). All the literature included within this review focused on traffic as the source of exposure.

Guarnieri and Balmes (2010) provide an in depth analysis of the current evidence available on the impact of outdoor air pollution on the development and worsening of asthma. The review indicated that short term exposure to traffic related air pollution can increase the likelihood of experiencing asthma symptoms. The available evidence suggests a clear link between the worsening of asthma symptoms and exposure to traffic related air pollution (Guarnieri and Balmes, 2010; Gasana,2012; Khreis et al, 2017). Greater disparity between research outcomes is found in relation to the impact of traffic related air pollution on the development of new onset asthma (Deng et al, 2016; Khreis et al, 2017). A meta -analysis conducted by Khreis et al (2017) found a link between exposure to traffic related air pollution and the development of asthma however the number of other studies supporting this conclusion is low. Gehring et al (2015) found that nitrogen dioxide 'may' increase the risk of developing asthma.

Research on traffic related air pollution can be based on the measurement of several different pollutants. Research can focus on solely on the impact of nitrogen dioxide, particulate matter or on a mixture of traffic related air pollutants. Khreis et al (2017) found a greater amount of studies focused on the impact of nitrogen dioxide on health however their meta-analysis indicated that it was not the most potent air pollutant but instead particulate matter or exposure to a mixture could be more harmful to health. In contrast, other research has found an association between nitrogen dioxide levels and health impact (Chiusolo et al, 2011., Chen et al, 2012., Ghosh et al, 2012., Cesaroni et al, 2013., Heinrich et al, 2013., Jerrett et al, 2013., Katsoulis et al, 2014., Mendala et al, 2016).

The most commonly used method of identifying respondents with asthma within the research was through questionnaires (Karakatsani et al, 2010; Haddad et al 2012; Kim et al, 2014). When using questionnaires, it important that only doctor diagnosed cases are included. The studies within this review have used a variety of different

methods to identify exposure to traffic related air pollution. The methods used have been generally grouped into the following categories:

- Levels of traffic related air pollution from a fixed monitoring station
- Using markers such as traffic level
- Using models to estimate levels such as land use regression models
- Monitoring individual levels of air pollution

All the methodologies mentioned above for collecting levels of traffic related air pollution have both positives and negatives. When levels are taken from a fixed monitoring station consideration is not given to the spatial variability of air pollution and therefore may not provide an accurate measure of residential exposure to air pollution levels (Khreis et al, 2017). This may over or underestimate a person's exposure. The Health Effects Institute (2010) in their review of the health effects of exposure to traffic related air pollution included a critical overview of the models used to predict human exposure. It found that certain models can be useful in estimating the spatial variation of traffic related air pollution. Some models allow for meteorological data and traffic variables to be input. Proximity models are criticised for their lack of consideration for factors affecting dispersion (HEI, 2010). Furthermore, the use of dispersion models was criticised by Williams et al (2011) for their tendency to over or underestimate the levels of air pollution. The Health Effects Institute have stated that hybrid models which measure personal exposure levels are the most reliable method of estimating human exposure (HEI, 2010).

The majority of the research on respiratory illnesses and particularly asthma have been completed with children. There is greater certainty that air pollution contributes to the development of asthma in children (Khreis et al, 2017) however this is not seen in adults. Children are often chosen as the subject of this research because they are a vulnerable group. Their respiratory and immune systems have not fully developed making them more susceptible (Deng et al, 2016). Furthermore, compared to their size they inhale a higher dose and have reduced nasal deposition compared to adults (Wright and Brunst, 2013). Some children may also spend more

time outdoors being active therefore having increased to traffic related air pollution (Khreis et al, 2017).

3.3.2.1.2 Other Respiratory Illnesses

In addition to asthma there have been various other respiratory symptoms associated with exposure to traffic related air pollution. Living less than 200 metres from a road was associated with wheezing in adults (Bowatte et al, 2017). The effect on traffic related air pollution on allergic airway disease was seen at very low concentration levels, substantially below the levels recommended within the World Health Organisation Guidelines (Bowatte et al, 2017). The levels of traffic related air pollution were identified by land use regression modelling.

Traffic related air pollution has also been linked to the number of incidences of lung cancer (Yorifuji et al, 2013., Nielsen et al,2013., Jerrett et al, 2013). Long term exposure to nitrogen dioxide was linked using a land use regression model to the number of participants diagnosed with lung cancer. Furthermore, the research indicated that the effect of PM_{10} and $PM_{2.5}$ could be seen below the current guideline level of 40µg m^{-3} and 20µg m^{-3} respectively (Yoriguji et al, 2013). Nielsen et al (2013) found particulate matter to be associated with an increase in lung cancer. Nitrogen dioxide levels and number of vehicles per day did not show any association with lung cancer diagnoses (Nielsen et al, 2013).

3.3.2.2 Cardiovascular Illnesses

The strength of evidence in relation to cardiovascular illnesses and exposure to traffic related air pollution has increased. The Lancet recently published research which linked traffic and coronary artery calcification which in turn can lead to an increased risk of having a heart attack or stroke (Kaufman et al, 2016_1). This study provides strong evidence of the impact of traffic related air pollution on cardiovascular health. The research screened over 7000 participants and took into consideration potential confounding factors such as age and socio economic status. Nitrogen dioxide and particulate matter were both found to impact on atherosclerosis, with particulate matter having a greater impact. The results of this study were then used to estimate the impact of certain levels of air pollution. The estimates indicated that if a resident moved from an area with an annual average of 11µg of particulate matter to an area

with 22µg, their development of atherosclerosis would increase by 38% (Kaufman et al, 2016[2]).

Exposure to nitrogen dioxide has been linked to incidences of heart disease (Jerrett et al, 2013., Katsoulis et al, 2014.,). Long term average levels of both nitrogen dioxide and particulate matter were associated with an increased risk of developing cardiovascular disease (Cao et al, 2011., Crouse et al, 2012., Katsoulis et al, 2014). A stronger association was found with research participants who were younger and for women (Katsoulis et al, 2014). However, there are also studies completed which have failed to determine a link between exposure to traffic and heart conditions. A review and meta-analysis concluded that the current evidence is not strong enough to determine a link between air pollution and heart failure (Shah et al, 2013). Further research also found no link between traffic related air pollution and heart disease (Puett et al, 2011., Ueda et al, 2012). There is some variation in results which indicates further research is required.

Hypertension also known as high blood pressure is another cardiovascular illness which has been associated with exposure to traffic related air pollution (Cai et al, 2016., Fuks et al, 2014., Yin et al, 2015., Wu et al, 2016., Chan et al, 2015). An association was found with residents living within 100 metres of a busy road (Fuks et al, 2014). A 10µg increase of particulate matter was found to increase in blood pressure (Chan et al, 2015). Cai et al (2016) conducted a meta-analysis which reviewed literature published until 2015. The review indicated that long term exposure to nitrogen dioxide and particulate matter was associated an increase in blood pressure. No association was found for short term exposure (Cai et al, 2016). A recent study measured indoor, outdoor and personal levels of $PM_{2.5}$ and found that the measured levels in each microenvironment were associated with hypertension (Yin et al, 2017). The research also took into consideration various confounding factors such as seasonal influences. The majority of research in relation to hypertension is focused on particulate matter therefore further research should consider the impact of nitrogen dioxide.

An association between exposure to traffic related air pollution and an increased risk of having a stroke is another health effect found within recent research (Yorifuji et al

2013., Sorensen et al, 2014., Anderson et al, 2012). Furthermore, research has found that exposure to nitrogen dioxide reduced the likelihood of a person surviving after having a stroke (Anderson et al, 2012., Maheswaran et al, 2010). Some of the research conducted has also considered the impact of air pollution in conjunction with noise from traffic. The combination of air pollution level and noise level had an increased impact than either of the pollutants separately indicating they work synergistically. The impact was found even at low concentrations as exposure to 10μg of nitrogen dioxide and 10db of road traffic noise led to an increased risk of experiencing a stroke (Sorensen et al, 2014). Another study also found that exposure to air pollution in conjunction with noise increased the risk of having a heart attack. Exposure to air pollution alone did not produce a significant association (Roswall et al, 2017).

In the research above, an effect was found between noise and air pollution, however there is further research which disagrees regarding the synergistic effect. There is agreement that road traffic in urban areas can lead to an increase in noise levels and air pollution levels. However, Fecht et al (2016) states that the mechanisms for the health effects of noise and air pollution differ. Noise can cause the release of stress hormones and interfere with sleep. In contrast, air pollution causes oxidative stress and inflammation. A low correlation between air pollution and noise at a roadside site in London which indicates determining the individual impacts may be possible. A critical review of current literature on the impact of noise and air pollution on cardiovascular health concluded that the impacts are distinct and are not completely dependent on each other (Tetreault et al, 2013). This conclusion was also supported by Stansfield (2015) who critically reviewed available evidence.

3.3.2.3 Pregnancy and Birth Outcomes

Pregnant women are considered a vulnerable group and there have been many studies conducted which state that exposure to air pollutants from traffic can impact on foetus development. Pregnant women have an increased vulnerability to air pollution due to their reduced immune response, inflammation and the nutritional requirements of the foetus increases the mother's sensitivity to oxidative stress. (Wang et al, 2016). Pregnant women who already have asthma or diabetes were

found to be even more susceptible to the effects of nitrogen dioxide (Mendola et al, 2016).

There is evidence that prenatal exposure to air pollution can lead to low or reduced birth weight (Shah and Balkhair, 2011., Padula et al, 2012., Winckelmans et al, 2015., Tu et al, 2016). Particulate matter exposure has been linked to a reduced birth weight in both pre-term and full-term births. For every 10µg m^{-3} increase the birth weight is estimated to be reduced by 39 grams (Winckelmans et al, 2015). This study used central monitoring stations to assign maternal exposure to particulate matter. Although an association was found, it should be viewed with caution as exposure may not be an accurate representation of actual exposure. Current literature suggests a potential link between exposure to air pollution from traffic and the pregnant women smoking or being obese as influential factors in low birth weight (Westergaard et al, 2017). These results should be viewed with caution as although a suggestive link it described the results were not statistically significant. There is also contradicting evidence that exposure to traffic related air pollution and specifically nitrogen dioxide can lead to an increase in birth weight. This research was conducted using an estimate of levels which were then input into a land use regression model (Bertin et al, 2015). Furthermore, Hjortegjerg et al (2016) and Laurent et al (2016) found exposure to nitrogen dioxide did not have any influence on birth weight. Clarity is required in relation to exposure and foetus birth weight.

In addition, pre term birth has also be identified by several researchers as an effect of exposure to traffic related air pollution. Exposure in the third and fourth trimester correlates to an increased risk, along with women who spend a greater number of hours at home (Padula et al, 2014., Estarlich et al, 2016., Mendola et al, 2016). Exposure to nitrogen dioxide was found to be linked to pre term birth when the mother had asthma with the critical exposure being between weeks 34-36. For particulate matter, critical exposure was found to be pre conception and in the early stages of pregnancy (Mendola et al, 2016). A study conducted in France observed an increased risk of pre-term birth with exposure to levels of nitrogen dioxide greater than 16µg m^{-3} for participants living in urban areas. In contrast, participants living in rural areas exposed to 16µg m^{-3} were not at an increased risk. This indicates that

traffic related air pollution may work synergistically with other pollutants or factors in the urban environment (Bertin et al, 2015). Gehring et al (2011) found no association between nitrogen dioxide and pre term. The impact of exposure to traffic related air pollution on pre term birth remains uncertain due to the lack of understanding in relation to the biological mechanisms and the lack of research which utilises measured air pollution levels rather than estimating levels. Further research is required in this area to identify critical exposure periods for pregnant women.

There is conflicting evidence of when exposure to traffic related air pollution is most harmful to pregnant women. There is evidence which states exposure pre-conception (Mendola et al, 2016), first trimester and in particular the first 4 weeks (Lee et al, 2014., Cai et al, 2017), final trimester (Rappozzo et al, 2014., Mendola et al, 2016) or multiple windows throughout the pregnancy (Gehring et al, 2011_a., Gehring et al, 2011_b). There is also research which has found exposure throughout the whole pregnancy to be linked to foetal development issues (Llop et al, 2010., Estarlich et al, 2016).

The majority of the studies reviewed above do not consider the biological mechanisms which make pregnant women more susceptible to the effects of traffic related air pollution. Slama et al (2008) found that due to maternal placental exchanges, the mother's immune system can be reduced, therefore leaving them more susceptible to the effects of air pollution. Furthermore, pregnant women may spend more time at home therefore if they live in a high pollution area, they may have a long exposure period (Choi et al, 2008).

3.3.2.4 Other Health Effects

There are several other health effects which have been linked to exposure to traffic related air pollution including diabetes, cognitive disorders, hospital admissions and mortality. The literature associated with each of these effects is discussed below.

3.3.2.4.1 Diabetes

There is a growing body of evidence linking air pollution emitted from traffic to the development of diabetes mellitus (Eze et al, 2015., Balti et al, 2014., Eze et al, 2014., Eze et al, 2013., Yan et al, 2013., Chen et al, 2013., Anderson et al, 2012., Coogan et

al, 2012., Puet et al, 2011., Dijkema et al, 2011., Kramer et al, 2010., Pearson et al, 2010.). Research conducted using mixed logistic regression modelling found associations with the number of people with diabetes and long term exposure to both particulate matter and nitrogen dioxide. The effects of both these pollutants were seen at concentrations below that recommended within the World Health Organisation Guidelines (Eze et al, 2013., Eze et al, 2014). Although both nitrogen dioxide and particulate matter have been linked to diabetes, a stronger association has been found with particulate matter. The research has also indicated that beta blockers may protect against the effect of particulate matter and the development of diabetes (Eze et al, 2014). Longitudinal studies have produced more consistent results on the impact of air pollution on diabetes (Karmer et al, 2010., Chen et al, 2013., Anderson et al, 2012., Coogan et al, 2012). Studies conducted in animals have also identified biological mechanisms for the effect of traffic related air pollution on diabetes. The evidence found particulate matter influences the insulin resistance in rats and the effect was heightened in rats which were obese (Yan, 2013). Further animal studies have identified that a high fat diet in combination with exposure to particulate matter can lead to insulin resistance (Sun et al, 2009., Xu et al, 2011). Even with animal studies confirming a link to diabetes there have been several epidemiological studies which have found no association with exposure and the development of diabetes (Dijkema et al, 2011., Puet et al, 2011). However, consideration must be given to the methods used within these studies. Their assessment of exposure and the covariates which the research considered may have affected the reliability of the results (Papazafiropoulou et al, 2011., Rajagopalan and Brook, 2012). Dijkema et al (2011) found no association with nitrogen dioxide or traffic density and the prevalence of diabetes type 2. In addition, a review stated that although there is evidence to suggest a link between air pollution from traffic and diabetes the evidence is currently not strong enough to determine causality (Thiering and Heinrich, 2015). Research has compared the impact which gender can have on the potency of air pollution and diabetes development. A review of evidence found that females were more likely to be affected by exposure to air pollution and develop diabetes type 2 (Eze et al, 2015). The review also identified the need for dose response studies to understand the impact of different concentrations of nitrogen

dioxide and particulate matter. This would also be useful in establishing safe exposure levels. The need to assess indoor exposure was also identified (Eze et al, 2015., Thiering and Heinrich, 2015).

3.3.2.1.2 Neurological health effects

The impact of living close to a road and developing neurological health effects is an emerging area of research, with the majority of research being completed within the last 5 years. A cohort study found that people living close to a road with heavy traffic were at an increased risk of developing dementia. Associations were found with both nitrogen dioxide and particulate matter levels however residential exposure levels were estimated (Chen et al, 2017). In addition, an in vivo study using mice found a link between diesel exhaust emissions and neurological issues. The results were seen from exposure to high levels of diesel exhaust emissions which may not be representative of real world driving conditions (Costa et al, 2017). In addition, a suggestive link was found between nitrogen dioxide and the incidence of Parkinson's disease. The effect was found at levels below that recommended within the World Health Organisation Guidelines (Lee et al, 2016). In addition, similar results were found in a study completed in Denmark which found exposure to nitrogen dioxide lead to a 9% increased risk of developing Parkinson's Disease (Ritz et al, 2015). Both of these studies are based on estimated nitrogen dioxide levels and medical records therefore greater investigation into biological mechanisms is required.

3.3.2.4.3 Hospital Admissions

Research linking an increase in traffic related air pollution and an increase in hospital admissions has been completed in various countries. The majority of these studies have used existing data sets on hospital admissions and analyse with historical records on the levels of nitrogen dioxide or particulate matter (Lagravinese et al, 2014., Dijkema et al, 2016., Capraz et al, 2017). Dijkema et al (2016) found that long term exposure was associated with increased admissions for both chronic obtrusive pulmonary disease (COPD) and asthma. Furthermore, Anderson et al (2012) found long term exposure was linked to COPD, asthma and also stroke with an increased risk with age. The increase in hospital admissions has mainly been found to be associated with those over 65 years of age (Chen et al, 2012., Bell et al, 2013). A 10µg

m^{-3} increase in nitrogen dioxide was found to increase the likelihood for admittance to hospital for respiratory and cardiovascular illnesses in China (Chen et al, 2012). Furthermore, an increase in hospital admissions were seen below the 40 µg m^{-3} legal limit for nitrogen dioxide which questions whether the limit is protective of health (Dijkema et al, 2016). However, the study only considered nitrogen dioxide which may affect the reliability of the results as people are exposed to a mixture of pollutants and specifically particulate matter which is also emitted from vehicles. Furthermore, the level of nitrogen dioxide was estimated for each residential area which does not consider the differences in personal exposure.

3.3.2.4.4 Mortality

In addition to hospital admissions, research has also linked exposure to particulate matter and mortality. Long term exposure to $PM_{2.5}$ was associated with natural cause mortality. The effect was seen even with residents exposed to levels of particulate matter below 20µg m^{-3} which is the current legally binding limit value for European countries (Beelan et al, 2014). This is further confirmed by Carey et al (2013) who found an increase in mortality with long term exposure to PM_{10}, $PM_{2.5}$ and nitrogen dioxide when modelled with the patient's postcode. The largest association was found to be deaths from respiratory illnesses and lung cancer (Carey et al, 2013). Further agreement in literature was found between exposure to nitrogen dioxide and particulate matter and mortality in various countries throughout Europe (Cesaroni et al, 2013., Hoek et al, 2013., Jerrett et al, 2013., Faustini et al, 2014., Fischer et al, 2015.,). A 10 µg increase in both nitrogen dioxide and $PM_{2.5}$ was found to impact on mortality (Hoek et al, 2013., Faustini et al, 2014., Fischer et al, 2015). The above evidence indicates that exposure to traffic related air pollution can cause premature death.

3.3.2.4.5 Effects of other pollutants

The majority of previous research focuses on the health impact of nitrogen dioxide and particulate matter. There also several other pollutants from road traffic that can impact on health. Ozone is not directly emitted from traffic but is formed through the reaction of nitrogen oxide and volatile organic compounds in the presence of sunlight. Ozone has been linked to the following health problems; irritation of eyes

and airways, increase in asthma symptoms and lung disease (DEARA, 2017). Carbon dioxide is also a pollutant associated with traffic. It is one of the most significant greenhouse gases. Carbon monoxide can also be emitted from vehicles. This pollutant can impact on the levels of oxygen in the blood stream and is particularly to those with existing heart conditions. However, it should be noted that the levels of carbon monoxide emitted from vehicles is unlikely to cause a health problem (EEA, 2016).

3.3.3 Personal Factors

There are various personal factors which can make a person more vulnerable to the negative effects of exposure to traffic related air pollution. These factors include age, gender, ethnicity and socio-economic status (Pinault et al, 2016). Furthermore, if a person smokes or is regularly exposed to second hand smoke they can be more vulnerable to the effects of air pollution (Westergaard et al, 2017).

The impact of socioeconomic status on exposure to traffic related air pollution is an area which has been heavily researched. Research participants from lower socio-economic backgrounds were found to be exposed to higher levels of air pollution (Hajat et al, 2015., Cakmak et al, 2016). However, conflicting evidence was found which indicated that a person with a low socio economic position (considering education level and occupation) were exposed to a lower level of nitrogen dioxide. This study incorporated over 5000 participants across Europe. The study did identify that locations with a high level of unemployment had higher levels of nitrogen dioxide. The results should be viewed with caution as the levels of nitrogen dioxide were estimated using a model which may over or under estimate exposure levels (Temam et al, 2017). Education level and household income are the two mostly commonly used indicators for socioeconomic status (Cakmak et al, 2016). The majority of these studies investigate air pollution exposure by assigning an air pollution for the area rather than considering individual exposure. The variability of air pollution means that there can be significant difference between individual exposure and the area average (Temam et al, 2017).

A person is also more vulnerable to the effects of traffic related air pollution if they have an existing medical condition (Goldberg et al, 2013., Thiering and Heinrich, 2015). Goldberg et al (2013) found that people with cardiovascular disease, hypertension and diabetes to be more vulnerable when exposed to nitrogen dioxide and particulate matter during short term exposure. Reliable studies will take into consideration the factors which have been identified in the studies mentioned in the above section.

3.3.4 What is a safe exposure level?

The majority of the research reviewed does not state the level of nitrogen dioxide or particulate matter at which health effects are seen. Therefore, it is difficult to determine what a safe exposure level is. The World Health Organisation have guidelines on ambient air quality which were created to protect against health effects. There is an increasing amount of literature indicating that health effects are evident below the levels recommended within the guidelines (Yoriguiji et al, 2013., Eze et al, 2013., Eze et al, 2014., Beelan et al, 2014., Lee et al, 2015., Dijkema et al, 2016., Bowatte et al, 2017). A review of the evidence supporting both the World Health Organisation guidelines and the European limit values needs to be completed which takes into consideration the new evidence. **Table 5** summarises the current levels stated within this literature search.

Table 5: Levels of Nitrogen Dioxide linked to Health Effects

Health Condition	**Author & Date**	**Nitrogen Dioxide Level µg m^{-3}**
Mortality	Cesaroni et al, 2013	Above 20 µg m^{-3}
Mortality	CARB, 2007	45.12
Mortality	Simpson et al, 2005	44.5
Mortality	Brook et al, 2007	19.34
Mortality & Cardiovascular Illnesses	Chiusolo et al, 2011	26-66

Mortality & Cardiovascular Illnesses	Chen et al, 2012	26-67
Cardiovascular Illnesses	Wong et al, 2008	44.7-66.6
Cardio-pulmonary illnesses	Heinrich et al, 2013	41
Cardio- pulmonary illnesses	Filluel et al, 2005	12-32
Cardio pulmonary illnesses	Schikowski et al, 2007	40
Birth defects	Cai et al, 2017	53-60
Pre term birth	Padula et al, 2014	23
Asthma	Bowatte et al, 2017	Below 40
Hospital Admissions	Dijkema et al, 2016	Greater than 31
Hypertension	Shan et al, 2014	***PM** above 58 µg m^{-3}
Lung Function	Karakatsani et al, 2010	44

Compared to the number of studies on air pollution and health, there are few studies which state the level of nitrogen dioxide at which health effects have been found. The majority of studies simply state 'exposure leads to health effects.' Future research needs to be more specific on the levels at which health effects can be found. This will provide evidence on whether the current limits are protective of health or if they should be reviewed.

Studies can misclassify the level of nitrogen dioxide exposure focusing on the outdoor concentration of the pollutant. Personal exposure to air pollution is the driver of health effects rather than residential ambient levels. Furthermore, the use of one level from a central monitoring station to assess a city-wide exposure also leads to the misclassification of exposure (Hoek et al, 2013). These inaccurate assessments of exposure have led to the current confusion and wide ranging literature on the

health impact of traffic related air pollution. Future research needs to consider the level of air pollution indoors and in other micro-environments.

3.3.5 Health Impact of Exposure to Traffic Related Air Pollution Summary

There is a vast amount of evidence available on the health effects associated with exposure to traffic related air pollution. There are various methods which have been used to identify associations between air pollution and health which has resulted in conflicting evidence. This review chapter has indicated that the reliability of the data collection methods needs to be considered when reviewing literature on the health impact.

The majority of the research mentioned above has not identified the biological mechanism by which nitrogen dioxide or particulate matter causes asthma within human anatomy. There are few studies which have investigated this (Gillespie-Bennett et al, 2011., Han et al, 2013). Gillespie- Bennett et al (2011) states that nitrogen dioxide has free radicals which can react with lipids, proteins and nucleic acids within the body. An in vivo study which exposed rats to nitrogen dioxide investigated the genotoxicity of the pollutant. The results found that exposure led to DNA breakages and changes to cells in brain, liver, spleen, kidney and heart (Han et al, 2013).

From reviewing the evidence, a link has been established with exposure to nitrogen dioxide, particulate or a mixture of traffic related air pollutants, with the following health conditions;

- **Respiratory Illnesses** including; asthma, lung disease, lung cancer, wheezing and shortness of breath
- **Cardiovascular Illnesses** including; heart disease, hypertension, stroke, chest pains and angina
- **Diabetes**
- **Cancer**
- **Pregnancy complications** including low birth weight

3.3.5.1 Literature Gaps

It is evident that there is a vast amount of research available on the health impact of air pollution. An increasing amount of research is being completed to identify the biological mechanisms behind exposure.

After reviewing the literature there were several research gaps identified. Future research should focus on;

- The number of hours spent at home and other exposure locations
- Identifying the number of people exposed to levels of air pollution that are higher than the objectives
- Identifying the health status of people within high pollution areas
- Identify individual exposure
- Identifying the level of air pollution which begins to impact on health
- Identifying a guideline level for exposure to indoor air pollution from traffic
- Identifying the biological mechanisms behind the damage caused by exposure to nitrogen dioxide and other traffic related pollutants

It is evident from reviewing the current literature that exposure to air pollution in some cases is not accurately identified. The majority of the research either uses an estimation of outdoor residential exposure using modelling techniques or centrally located monitoring stations which may be located some distance from the research participant. Air pollution, and in particular nitrogen dioxide, has a high variability. It varies both spatially and temporally and not considering this leads to the misclassification of individual exposure.

Traffic related air pollution is impacting on human health with strong evidence linking exposure to respiratory and cardiovascular illnesses. Future research requires air pollution levels to be monitored for a greater understanding of personal exposure. People who are exposed to traffic related air pollution for short periods of time are at risk as well as those who experience longer term exposure. The impact can be seen through all age groups, with exposure beginning in the womb. Health effects are evident across all age groups but can be influenced by factors such as socioeconomic status. Although some literature gaps exist, it is evident that health

effects can be associated with exposure to traffic related air pollution. Taking into consideration the impact which exposure to traffic can have on health it is important that the public are aware of the health impact. Section 3.4 will consider public awareness, concern and knowledge of traffic related air pollution and its impact.

3.4 Awareness, Knowledge and Perception of Air Pollution

Section 3.3 critically reviewed the health impact of exposure to air pollution from traffic. It is evident from current available literature that health effects can be seen from both short term and long term exposure to nitrogen dioxide and other pollutants from vehicles. In particular, strong evidence exists on the respiratory and cardiovascular impact of exposure. As evidence exists on the health impact of exposure of traffic related air pollution, the next consideration is whether the public are aware of their exposure and its potential impact on their well-being. Furthermore, whether awareness leads to behaviour change. This section reviews the current literature available on environmental concern and in particular the public's awareness and concern about traffic related air pollution. It is important to identify public knowledge for appropriate interventions to be designed and to identify the level which information should be communicated.

3.4.1 Search Strategy

To ensure a comprehensive search of information was completed, a search strategy was devised. The search terms are detailed below. The search strategy is adapted from a critical review completed by Oltra and Sala (2013).

The search terms for;

Air Pollution

'traffic related air pollution', 'TRAP', 'air pollution', 'vehicle emissions'

AND

Awareness and Knowledge

'awareness', 'perception', 'knowledge', 'public views', 'public understanding',

Concern

'environmental concern', 'environmental health risk', 'public concern', 'risk perception'

Communication

'risk communication', 'information', 'resources', 'environmental information'

The literature search was completed using the following databases: 'Scopus' and 'Science Direct'. Any articles published not published in English were excluded from the review.

The results of the literature review are presented in key themes;

1) Awareness of traffic related air pollution
2) Knowledge and understanding of air pollution
3) Public Perception of air pollution
4) Public Concern about air pollution
5) Risk Communication and Public Information

Below each of these themes are discussed along with the relevant literature. The research gaps are stated at the conclusion of the chapter.

3.4.2 Awareness of Traffic Related Air Pollution

Awareness is defined as, *'knowledge that something exists, or understanding of a situation or subject at the present time based on information or experience'* (Cambridge University Press, 2017). Taking into consideration this definition, awareness of air pollution would include a knowledge that air pollution exists based on either information read or experience of adverse effects from exposure. Understanding the public's awareness of air pollution is important as knowledge often leads to action.

Previous research on environmental behaviour change has identified awareness of the impact as a factor. For example, research conducted on climate change found that understanding the causes of climate change motivated the public to reduce their impact on the environment (Bord et al, 2000., Halady et at, 2010). This indicates that increasing awareness and knowledge of air pollution may help to bring

environmental behaviour change. This section identifies the current research conducted on awareness and the current gaps in literature.

The majority of previous research completed in the field of air pollution perception was completed in the 1960s-1970s. The focus of the research at this time was on coal burning from industry and households. The research (Rankin, 1969., Billingsley, 1974/1975., Auliciems and Burton, 1971., de Groot, 1967; Shusky, 1966) found that public awareness of air pollution was low even when exposed to high levels. Since these studies have been completed, the amount of information available has increased and there is often media coverage of the impact of air pollution. In addition, the main sources of air pollution have changed. Up to date data on public perception and awareness of air pollution needs to be collected.

The research completed during the 1960s-1970s had several limitations. The research specifically focused on public awareness and did not gather further data on personal circumstances such as socio-economic status or distance to the polluting source. The research did not provide an understanding of how and why people perceive air pollution differently (Bickerstaff and Walker, 2003). Research on perception of air pollution continued within the 1990's. The focus of the research had shifted to identifying how to communicate air pollution information to increase awareness of air pollution issues. Oltra and Sala (2013) have demonstrated how awareness and perception studies have developed over the past 50 years. Their findings are summarised in **Table 6.**

Table 6: The Development of Perception Based Research in the field of Air Pollution

Year	Research Objectives
1950s-1960s	• Identify awareness of air pollution • Cognitive dimension of air pollution
1970s-1980s	• Few research studies completed – air pollution was not a policy priority • Comparison of human perception and air pollution levels
1990s	• Identifying how to effectively communicate the risk of air pollution exposure
2000s	• Considered the factors which influence people's perceptions including social factors, politics and culture

Source: Oltra and Sala, 2013

The awareness of air pollution was investigated in several countries in Europe (Eurobarometer 360, 2013). It identified that 59% of those surveyed felt that they were uninformed about air pollution issues in their country. However, exactly 50% of those surveyed thought the air quality in their area had declined within the last decade (Eurobarometer 360, 2013). This research indicates that people want to be more informed about air pollution. In addition, it indicates that people are aware of air pollution as an issue and the increasing levels. Bickerstaff and Walker (2001) investigated where people thought air pollution levels are the highest. The majority of respondents stated air pollution levels are highest in the city with reasons such as lack of greenery and litter given.

The main methods which the public use for identifying air pollution levels have been investigated (Wakefield et al, 2001., Bickerstaff and Walker, 2003., Moffat et al, 2009., Claeson, 2013). The methods identified include; visual, smell, health impacts (e.g. asthma symptoms), annoyance and television or radio broadcast. The ability to identify air pollution in the United Kingdom through vision from the presence of smoke or smog or through smell is rare. Technological advances have meant that air pollution has largely become an invisible problem. A more common method of identifying air pollution now is through the knowledge of others during informal conversations or social media posts (Oltra and Sala, 2013). Personal sharing of information can inform others and increase awareness. In addition, people who have

experienced health symptoms or have seen air pollution are more likely to be conscious of exposure. Sensory experiences of air pollution have been described as 'critical' in shaping a person's attitude towards air pollution (Bickerstaff and Walker, 2003., Cole et al, 1999). The question that exists now is how to increase the awareness of those who do not experience symptoms and who are exposed to invisible sources such as vehicle emissions.

Previous research has identified study locations based on various factors. Examples of these factors include socio-economic status of the residents (including educational attainment and income) and proximity to sources (Bikerstaff and Walker 2001). Previous research has not specifically focused on residents living in Air Quality Management Areas who are exposed to levels of air pollution above the legally binding air quality objective or been completed in Northern Ireland. The majority of previous research has been completed in major cities such as Birmingham (Bickerstaff and Walker, 2001). Furthermore, previous research has generally considered air pollution rather than focusing on one source such as traffic (Bickerstaff and Walker, 2001., Moffat et al, 2009., Claeson, 2013).

The perception and awareness of air pollution has been considered in isolation. Previous research has failed to collect measurements of local air pollution levels (Wakefield et al, 2001., Bickerstaff and Walker, 2003., Moffat et al, 2009., Claeson, 2013., Oltra and Sala, 2013). The measurement of air pollution levels and awareness data would allow for greater understanding of whether those who are exposed to higher levels have a greater awareness. Awareness of air pollution levels is important, so people can make the choice to reduce their personal exposure (Cisneros et al, 2017). Choices can include choosing a different route to work or choosing not to open the windows at their house during rush hour. Awareness can encourage people to make small changes to reduce their exposure.

3.4.3 Knowledge and Understanding of Air Pollution

This section focuses on the current literature available on public knowledge of traffic related air pollution. In particular, public knowledge of the health impact of exposure to air pollution from traffic. In addition, a review of current evidence on public

awareness of the interventions in place to reduce air pollution such as local air quality management is included.

Previous research has found that knowledge of the sources and personal exposure to air pollution is low. In relation to transport, Bikkerstaff (1999) found that people didn't consider their contribution to traffic related air pollution but instead fault was given to buses and 'other' commuters. Research conducted by Smallbone (2010) found that half of those surveyed could identify an air pollutant with the most common answer carbon dioxide. Carbon dioxide may be the most commonly selected pollutant because of the attention it has received particularly from the government as they strive to meet greenhouse gas targets. A recent study in California found participants were able to identify transport as the most significant source in their area (Cisneros et al, 2017). Over recent months there has been greater attention given to 'dirty diesels'. Future research may consider the impact which rising media attention from the Volkswagen scandal and the client earth court battle on raising the knowledge and awareness of the public.

Knowledge of the levels of air pollution has been explored among urban and rural dwellers. Those living in rural areas are less likely to perceive their air pollution levels as bad. Only residents living close to a major pollution source such as a motorway, identified their exposure to air pollution to be bad (Smallbone, 2010). However, evidence has also found that people perceive their area to be better than other areas (Brody et al, 2004). Due to the familiarity of the sources they do not consider them to be of concern.

Knowledge of the health effects associated with exposure to air pollution has been investigated by several researchers (Smallbone, 2010., Van den Elshout, 2008., Howel et al, 2003., Bickerstaff and Walker, 2001., Wakefield et al, 2001). Smallbone (2010) identified that the public are aware of the impact on respiratory illnesses. However, a low level of knowledge was found in relation to other health impacts such as cardiovascular illnesses. People with cardiovascular illnesses were also found to have a low level of awareness regarding the impact of exposure to air pollution on cardiovascular health (Smallbone, 2010). Public knowledge in relation to respiratory illnesses shows some improvement amongst the public, as research completed in

2001 has shown a lack of knowledge in relation to all health effects (Bickerstaff and Walker 2001., Wakefield et al, 2001). The health impact of air pollution can be seen as an impersonal risk to those who do not experience immediate symptoms. Research found that they consider it of little personal relevance and often deny the health impact which it could be having. They perceive the risk from air pollution to be low compared to those with health conditions (Van den Elshout, 2008). Furthermore, people seem unaware of how exposure to air pollution can contribute as a cause to developing chronic illnesses such as asthma. People are more aware that symptoms can be exacerbated but fail to understand that they can be affected even if they do not have an existing illness (Howel et al, 2003).

3.4.4 Perception of Air Pollution

Perception has been defined by Oltra and Sala (2014) as: '*the subjective judgment by which the individual understands and gives a meaning to a particular threat or hazard.*' The judgement is made by individuals deliberating the harmful effects with their perceived benefits. People's views are often shaped by their personal circumstances such as educational status, socio-economic factors and cultural background. Perception is an important factor in whether a person responds to preventive measures. How a person perceives the air quality in their area is a determinant of whether they will consider changing their behaviour to reduce exposure (Pantavou et al, 2017., Berry et al, 2011). Identifying public perception should be completed before designing interventions to reduce air pollution.

Perceptual experience has been identified as foundational in shaping the public's opinions on air pollution. Direct experiences such as visual or noise disturbance are linked to a greater awareness of air pollution. Pantavou et al (2017) found that people living in the Mediterranean associated the level of visible dust with the level of air pollution. People have been able to perceive high levels of particulate matter pollution better than any other pollutant (Nikolopoulou et al, 2011). The empirical data collection for Nikolopoulou et al (2011) study was collected in close proximity to a building site, where a high percentage of the participant rated the air quality as poor. It should be investigated whether the results would be similar in close

proximity to road with a high traffic volume. The impact of place and surrounding on perception of air pollution has been found to be influential (Nikolopoulou et al, 2001., Day, 2007., Bonnes et al, 2007., Brody et al, 2007). Experiencing effects to health from air pollution has also been associated with an increased awareness (Oltra and Sala, 2014).

Understanding an individual's risk perception is multifaceted due to the various influencing factors such as the nature of the risk and personal circumstances. The literature (Oltra and Sala, 2014) divides the factors into three groups: risk related factors, psycho-social factors and institutional and contextual factors. Risk related factors are the characteristics of air pollution which affect how people perceive it for example it is invisible (Oltra and Sala, 2014). Psycho-social factors is how different groups of people perceive the risk for example gender, education and age can all be influencing factors (Kim et al, 2012., Egondi et al, 2013., Huang et al, 2017). Contextual factors are how a person's circumstances can influence air pollution. Health status has been one of the more widely researched aspects and there is agreement that people with health problems are more concerned about air pollution (Oltra and Sala, 2013).

There have been several studies which have investigated people's perception of both indoor and outdoor air quality. The studies have shown that people's perception of air quality does not relate to the measured levels of air pollution (Semenza et al, 2008., Dorizas et al, 2015). This indicates that the psycho-social and contextual factors are more influential on a person's perception of air pollution than the levels of air pollution which they are exposed to. Negative perceptions of air quality seem to be felt by those which have experienced the effect of poor quality such as a health effect or smog (Nikolopoulou et al, 2011., Pantavou et al, 2017). In addition, some studies have found the public perceive high temperatures with poor air quality (Zhang et al, 2011., Dorizas et al, 2015).

Research completed has identified several personal factors which generally are associated with greater concern about issues. This includes gender, women have been shown to worry more about environment issues than men (Oltra and Sala, 2013., Cisneros et al, 2017). In addition, age is another factor. Older people were

more likely to consider air pollution to be worse. If a person has children, they were also found to be more concerned about the potential impact (Oltra and Sala, 2013). People who smoke have been more likely to perceive the air quality in the environment to be good and therefore are less aware of their exposure (Nikolopoulou et al, 2011). Other factors include education, occupation, income and marital status (Oltra and Sala, 2013).

A person's attachment to the area they live in has been found to be influential in their perception of air pollution (Bikkerstaff and Walker, 2001., Wakefield et al, 2001., Collins and Koplan, 2009). People who are not attached to their area, tend to have more negative views about the air pollution levels (Bikkerstaff and Walker, 2001). Perception of air pollution has been found to be highly influenced by a person's overall perception of their community. It can be influenced by the impact of other factors such as crime and rubbish. The presence of other concerns influences their opinion on air quality more than any other information they have received (Collins and Koplan, 2009). It has been suggested that people do not have 'factual knowledge' about air pollution but rather their own thoughts and perceptions (Willet, 2010).

A study conducted in California with over 700 residents found that people had the ability to identify high levels of particulate matter more than any other pollutant. When levels of $PM_{2.5}$ were high, the participants were more likely to perceive the air pollution in their area as poor (Cisneros et al, 2017). The results from Claeson et al (2013) agree with the findings however these results are in the minority. The reason for the higher perception rates found by Cisneros et al (2017) may be due to the media attention air pollution levels receive in the San Joaquin Valley area of California. The majority of studies have found that people's perceptions of air pollution are different from average monitored levels (Kim et al, 2012., Johnson et al, 2012., Semenza et al, 2008).

In the field of air pollution perception, the number of studies which have measured air pollution levels and people's perceptions is low (Brody et al, 2004., Nikolopoulou et al, 2011., Cisneros et al, 2017). The majority of epidemiologic research has focused on identifying health effects rather than considering the public's perception of the

levels. In the studies where the level of air pollution is monitored, the results are usually from a central monitoring station. One station is usually used to cover a whole city, town or community (Brody et al, 2004., Cisneros et al, 2017). This does not take into consideration the personal level of exposure. It is important to monitor the levels of air pollution due to the spatial and temporal variation of air pollution and in particular nitrogen dioxide. None of the studies included within this review identified a threshold level. Identifying a threshold would indicate at what level people begin to realise that air pollution levels are high. Identifying a threshold value should also coincide with determining how people have come to their conclusion for example visual and temperature.

Xu et al (2017) commented that attitude towards air pollution levels is socially constructed and therefore advised that studies need to be completed locally. This is due to the social factors differing between locations. There is currently no available literature on the public perception and attitude towards traffic related air pollution in Northern Ireland.

In summary, a person's perception of air pollution is formed from a complex combination of factors socio economic factors, cultural factors and personal factors. Often perceptions are not based on factual information therefore can often be misinformed. Consideration needs to be given to how to influence a person's perception of air pollution.

3.4.5 Public concern about air pollution

There is a lack of current research on the public's concern in relation to air pollution. The majority of previous research focuses on the general subject of environmental concern. Environmental concern can be defined as investigating how aware people are of environmental issues (Dunlop and Jones, 2002). Currently within Northern Ireland the Department for Agriculture, Environment and Rural Affairs (DAERA, 2017) complete a survey on the Environment. The results of the research have indicated that concern for air pollution has declined. There was a greater number of participants concerned about traffic emissions in 2003 than in 2015. The research does not focus on any particular group or consider factors such as health condition and age therefore more detailed information is required.

There is conflicting evidence on factors which are thought to influence the level of concern. Several studies have found that residents living in areas with high levels of air pollution were more likely to be concerned about air pollution than those living in low pollution areas (Brody et al, 2008., Zheng et al, 2013). The research conducted by Zheng et al (2013) was completed in China where the impact of air pollution can produce visual effects such as smog. Therefore, this needs to be considered when comparing the results with other studies. Bush et al (2001) found that residents interviewed were unlikely to mention air pollution as a concern in their area even if they lived areas with high levels of air pollution. This indicates that there are various factors which interact to form a person's level of concern and therefore is not only dependent on their level of exposure. Liu and Mu (2016) identified that age, gender, income and location are all influential in building a person's level of concern about air pollution. These factors are similar to those which influence perception and awareness of air pollution.

Cisneros et al (2017) asked research participants to identify the top concerns in their area. Respondents who were exposed to high levels of particulate matter were more concerned about air pollution with the majority ranking air pollution as a serious concern. The residents who were exposed to lower levels of particulate matter were less likely to state air pollution in their top three concerns. This indicates a high level of awareness among the residents in California. In contrast, other research has found that people are unlikely to spontaneously identify air pollution as one of their concerns. This has also been found in areas were air pollution levels are high (Oltra and Sala, 2013). As air pollution is invisible, people tend not to identify it as much as issues which are clearly visible or audible in their area. It is important to identify public concern as concern about an issue is often as precursor to taking action.

Xu et al (2017) investigated the reasons why people where not concerned about air pollution. The study was completed in China where air pollution levels are often very high and produce a visible smog. One of the reasons participants gave for their lack of concern was they felt their individual actions would not influence the levels of air pollution or their exposure therefore they did not worry about it. In addition, there was also an attitude that exposure to air pollution is to be expected when living in a

large city. They felt the benefits of living in the city outweighed the negative environmental exposure. This research also asked respondents whether they would consider not using their car on high pollution days. The responses indicated that people did not feel personally responsible for the air pollution and felt that not using their car would be ineffective and inconvenient. This indicates that there needs to be greater motivation for the public to participate in mitigation.

3.4.6 Risk Communication and Public Information

This section reviews the current literature available on the effectiveness of public information on reducing exposure to air pollution. Air pollution information is communicated to increase public knowledge but also to ignite behaviour change. Consideration needs to be given to the message, the audience and the method used to communicate the information. Difficulty is often found in changing habits and making lasting change (Oltra and Sala, 2015).

3.4.6.1 Legal Requirement to report air pollution levels

Within the United Kingdom air pollution levels are monitored using real time automatic monitoring stations. Under European legislation (EU Directive 2008/50/EC) each country is required to make the levels of monitored air pollution available to the public. In addition, when levels are above the recommended European objective, a text alert is sent to registered users. The following information is also required under European legislation; the potential health effects from exposure, vulnerable groups, actions which can be taken to reduce exposure and recommended preventive action. These are some of the examples of information which is communicated to the public about air pollution levels usually in the form of a website. A Spanish study recently investigated why air pollution information was produced by local authorities. The majority stated that it is required under law (Oltra and Sala, 2015). If the requirement was not prescribed under law it is doubtful that the information would be made available to the public. Consideration needs to be given to this within the United Kingdom due to the potential implications Brexit could have on environmental legislation. Furthermore, the information provided should be examined to determine whether any more than the legal requirement is produced or whether the information is distributed.

To ignite a change in behaviour increasing public awareness and knowledge is often the first step (Oltra and Sala, 2014). Research conducted by Semeenza et al (2008) found that government warning systems such as the text alert service, have not been effective in changing behaviour even in circumstances were levels are reported as 'very high'. There have been few researchers than have studied the effectiveness of public information. Johnson (2012) found that few people used the information produced by government agencies on air pollution levels, with many responding that they identified air pollution levels through their senses. Wartenberg (2009) identified several problems which are affecting the communication of air pollution information. Often air pollution information can be technical by giving details of levels and the objectives. This information is not easily understood by the public. In addition, it has also been found there is a lack of interest from those who are receiving the information. The research concluded that communication of air pollution information needs to carefully consider the audience and the medium used to deliver the information. In addition, it was suggested that information should be piloted with a number of the target audience. This research was completed over seven years ago therefore a more recent review of current information is required.

3.4.6.2 Is current communication effective?

A European wide study found that 59% of people do not feel there is adequate information on air pollution levels (Eurobarmeter 360, 2013). A review completed in Spain identified all the current methods of communication and the type of information which was being communicated (Oltra and Sala, 2015). The results indicate that levels were being communicated via a website and text alert system, annual reports education programmes were being conducted in schools and public enquiries were responded to. Furthermore, in larger cities electronic street panels were being used to display air pollution levels which reaches all members of the public. The text alert service has been criticised as it may not reach the general population due to low numbers using the service and the potential for the majority to be from a vulnerable group as this is who the service is aimed at (Oltra and Sala, 2015). The information mentioned within the review identifies numerous methods of communicating air pollution levels but identifies few ways in which preventative information is communicated. A review of the current information available on air

pollution in Northern Ireland needs to be completed to identify the current gaps in available information. In addition, current research has not evaluated the effectiveness of information. Views have been collected from professionals but the impact on public knowledge and awareness has not been collected.

Bikerstaff and Walker (1999) found that people were not in search of information on air pollution or using it on a regular basis. This research was completed when the majority of information sources would have been the media or in paper format. Consideration also needs to be given as to whether people want more information. It has been found that very few members of public actually use the information currently available (Oltra and Sala, 2014). Investigation into the reasons why the resources are not used needs to completed before a continuation of similar unused resources is produced. Up to date research is required on the adequacy of current information on air pollution.

Current available information assumes that behaviour change will occur when people are more informed and have a greater understanding of the risk. This is called the '*knowledge -deficit model of behaviour change'* (Shultz, 2002). This assumes that when a person is alerted to a high level of air pollution they will change their behaviour to reduce their risk of exposure or reduce their contribution to air pollution levels. The model identifies that knowledge is required for behaviour change but fails to consider the other two factors identified by Oltra and Sala (2014), psycho social factors and contextual factors. The knowledge deficit model for behaviour change is a simplistic view of what is required to change behaviour. Information can increase awareness but this is not always sufficient to lead to intention, action and behaviour modification (Oltra and Sala, 2014).

There is currently a lack of research on the effectiveness of communicating air pollution information. Smallbone (2010) found that the public trusted information from the Environment Agency more than the information published by central government. The Environment Agency, due to its name, was identified by the public as being a key contact for environmental information. This indicates the perceptions of the public and their lack of awareness of government agency responsibilities. The

Environment Agency are not responsible for monitoring or reporting on air pollution levels.

The European Commission (2013) conducted research on what the public felt their contribution could be reducing air pollution levels. Suggestions included reducing car use and using energy efficient appliances. Furthermore, additional information on the health effects of exposure was suggested. This is thought to motivate action when people are aware of the impact of their actions. The research did not consider their opinions on the interventions already in place by the government to reduce air pollution. Previous research completed on government interventions has focused on the views of those enforcing them rather than the public. This a gap within current literature.

3.4.6.3 Innovative communication methods

In recent years there has been the emergence of 'citizen science' or community based participatory research. This technique engages members of the public in air pollution research with the ambition that participation will lead to understanding of air pollution levels and therefore behaviour change. Members of the public are involved in the data collection process for example distribution of diffusion tubes. This in turn is expected to increase understanding (Wiggins and Crowston, 2011., Brown et al, 2012., Bonney and Dickinson, 2012). This method involves a two-way communication process and public engagement. There are challenges and limitations within citizen science projects such as lack of volunteers and data reliability. As volunteers are involved with empirical data collection, the consistency and reliability of results can be compromised (Oltra and Sala, 2014).

3.4.6.4 Summary

There are many barriers to effectively communicating air pollution information which have been identified in recent literature (Saksena, 2011., Johnson, 2012., Vallejos and Onate, 2013., Taylor and McMillun, 2013). The low level of public awareness about air pollution and the current services available means that resources are often not used and are therefore ineffective at engaging the public (Saksena, 2011). Concerns have been raised about whether the information produced reaches the general public (Oltra and Sala, 2015). The public have found the information too technical

and the behaviour changes required to complex which has resulted in a low level of progress being made (Sexton, 2011). The internet is often used to communicate air pollution information. Concerns have been raised about the effectiveness of using websites. The websites rely on passive transmission rather than proactively promoting the information (Oltra and Sala, 2015). There have been few reviews regarding the quality of information provided (Chen et al, 2013., Gonazalez Ortic, 2013., Plaia and Ruggieri, 2011). The research has shown that the majority of European Countries are complying with legislation by providing information on the levels of measured air pollution. Although it is being provided, the research has indicated that it needs to be promoted to the public. The media has been suggested as a route which could increase the diffusion of air pollution information (Gonazalez Ortic, 2013). From reviewing the literature available, the majority of studies have found that governments are producing information on the levels of air pollution but proactive information on reducing air pollution levels is rare.

One of the questions raised in air pollution communication literature is; how can the communication of information to the public be improved? It is often answered with more information. However, if the public are not engaging with the information, research on the reasons behind it are required. This would allow for an evidence based approach to developing air quality information (Oltra and Sala, 2015). The review of current information identified the following problems with current information provision;

- Too technical
- Requires complex behaviour change
- It isn't focused to the target audience
- Relies on the public to search for the information

There are still many questions in regards to the communication of air pollution information. Who is the target audience? Is information focused on vulnerable groups or is it for the general population? Is there information on how an individual can reduce their impact on air pollution? What information do the public want? Is current information effective?

Information alone will not reduce the levels of traffic related air pollution enough to comply with the levels set in legislation. There needs to also be technological advances in relation to emissions from vehicles and tighter regulations.

3.4.7 Key Findings and Current Literature Gaps on Awareness and Perception of Air Pollution

Awareness, perception and knowledge are all components which need to be understood as a pre-cursor to change in attitudes among the public. This chapter has heavily relied on research which was completed over a decade ago. This indicates the lack of recent research in the area and therefore the need for it within future research.

From reviewing the literature on perception, concern and knowledge of air pollution it is evident that there are still several gaps in literature which need to be addressed. In particular, focus needs to be on traffic related air pollution and residents within Northern Ireland. Previous research has provided a broad overview of air pollution but has failed to provide detailed information on exposure to a particular source or exposure of a certain community. If the level of awareness and concern of residents is unknown, it is difficult to design effective interventions and therefore reduce air pollution levels.

After reviewing the relevant literature on awareness, concern and knowledge of traffic related air pollution, there were several gaps in literature identified which are outlined below.

- Previous research on awareness of air pollution has been completed when the main sources of air pollution were different. Up to date information is required which focuses on awareness of traffic related air pollution.
- Current literature on concern focuses on a more general theme of environmental concern. Greater detail is required which focuses specifically on air pollution
- Knowledge about the health impact of traffic related air pollution has focused on the general public or those with an existing health condition. There was

currently no existing literature on those living within air quality management areas or with an existing medical condition

- Current literature has failed to combine research on awareness with monitoring of pollutant levels
- The effectiveness of current information available to the public at increasing awareness and knowledge
- Of the literature reviewed, none of the data has been collected in Northern Ireland therefore this a current gap in literature. It cannot be assumed that residents within Northern Ireland have the same level of knowledge or exposure as those within other parts of the United Kingdom.

3.5 Summary

Air pollution is currently a widely researched area. From reviewing the literature there are still numerous research gaps in various areas. The current literature gaps are summarised below;

- The effectiveness of Local Air Quality Management in Northern Ireland
- Monitoring of traffic related air pollution – there is a still a large proportion of current research completed using models or estimates of air pollution levels
- Indoor and Outdoor monitoring – the majority of previous research relies on outdoor measuring.
- Identifying the number of people exposed to levels of air pollution which do not meet the limit values
- Identifying the health status of people within high pollution areas
- Accurately identifying individual exposure
- Identifying the biological mechanisms behind the damage caused by exposure to nitrogen dioxide and other traffic related pollutants
- Previous research on awareness of air pollution has been completed when the main sources of air pollution were different. Up to date information is required which focuses on awareness of traffic related air pollution.

- Current literature on concern focuses on a more general theme of environmental concern. Greater detail is required which focuses specifically on air pollution
- Knowledge about the health impact of traffic related air pollution has focused on the general public or those with an existing health condition. There was currently no existing literature on those living within air quality management areas or with an existing medical condition
- Current literature has failed to combine research on awareness with monitoring of pollutant levels
- The effectiveness of communicating air pollution information needs to be reviewed
- Of the literature reviewed, none of the data has been collected in Northern Ireland therefore this a current gap in literature. It cannot be assumed that residents within Northern Ireland have the same level of knowledge or exposure as those within other parts of the United Kingdom.

It is evident that there are multiple existing gaps in literature. This thesis could not address all these current gaps therefore several were selected to focus on. The gaps which were selected for further investigation in this research were chosen taking into consideration the knowledge and skills of the researcher.

- The effectiveness of Local Air Quality Management System in reducing the levels of traffic related air pollution in Northern Ireland
- Measuring the levels of Indoor and Outdoor air pollution
- The health status of people living in high pollution areas
- Recent information on the public's awareness of air pollution levels and the impact of exposure
- Combining assessing the awareness of air pollution with the measurement of air pollution levels
- Review of air pollution communication techniques and their effectiveness in engaging the public
- Research on air pollution in Northern Ireland

Taking into consideration these gaps in literature, the methodology was designed. **Chapter 4** states the methods used during the empirical data collection stage and states the rationale for the methods chosen.

The current literature gaps are summarised below;

- The effectiveness of Local Air Quality Management in Northern Ireland
- Monitoring of traffic related air pollution – there is a still a large proportion of current research completed using models or estimates of air pollution levels
- Indoor and Outdoor monitoring – the majority of previous research relies on outdoor measuring.
- Identifying the number of people exposed to levels of air pollution which do not meet the limit values
- Identifying the health status of people within high pollution areas
- Accurately identifying individual exposure
- Identifying the biological mechanisms behind the damage caused by exposure to nitrogen dioxide and other traffic related pollutants
- Previous research on awareness of air pollution has been completed when the main sources of air pollution were different. Up to date information is required which focuses on awareness of traffic related air pollution.
- Current literature on concern focuses on a more general theme of environmental concern. Greater detail is required which focuses specifically on air pollution
- Knowledge about the health impact of traffic related air pollution has focused on the general public or those with an existing health condition. There was currently no existing literature on those living within air quality management areas or with an existing medical condition
- Current literature has failed to combine research on awareness with monitoring of pollutant levels

- The effectiveness of communicating air pollution information needs to be reviewed
- Of the literature reviewed, none of the data has been collected in Northern Ireland therefore this a current gap in literature. It cannot be assumed that residents within Northern Ireland have the same level of knowledge or exposure as those within other parts of the United Kingdom.

Chapter 4: Methodology

4.1 Introduction

The previous chapters have systematically reviewed the current evidence available on exposure to traffic related air pollution and the potential health impact. In addition, the legislative background and a critique of the management of air pollution has been included. After gaining an understanding of the current literature, research gaps were identified and aims and objectives were established.

Further detail on the methodological approaches used in the research is provided in this chapter. The reasoning for the methods chosen is supported by a review of the methodological approaches used in previous studies which measure the impact of traffic related air pollution. Appraising the previous methods ensures that the most appropriate methodology is chosen.

This chapter elaborates on the reasoning for the chosen approaches for both monitoring nitrogen dioxide levels and collecting qualitative and quantitative data from the research participants. An overview of the statistical methods for analysing data is included. This chapter aims to meet the following objectives;

- Consider the methods used in previous research on traffic related air pollution
- Develop a methodological framework
- Identify an appropriate method for data collection which will meet the aims and objectives of the research
- Defend the method used to analyse the data

4.2 Research Approaches

There are three main approaches used in research: qualitative, quantitative and mixed method. The quantitative approach can be defined through three of its key features: measurement, quantification and reliability (Robson and McCarton, 2016). Quantitative data involves collecting and analysing data in a numerical form (Blaxter et al,1996). Examples of frequently used data collection methods for quantitative

data are experiments and surveys. Quantitative data collection is used by many researchers for its reliability and its ability to produce findings which can be generalised to a population and reproduced (Greenhalgh and Taylor, 2007., Burns, 2000).

The qualitative approach often involves collecting more detailed information from a smaller number of research participants (Blaxter et al, 1996). Qualitative data is particularly useful for collecting contextual information and for obtaining the research participants' emotions and motivations. In addition, collecting detailed information on participants' perceptions of a situation and their reasons for behaving in a certain manner is common in qualitative research (Gray, 2014). Qualitative data can be collected using various methods including observations, interviews, questionnaires and document analysis. Questionnaires and interviews collecting qualitative data uses open ended questions without set out responses (Creswell, 2014). Once data is collected, the information can be organised into themes (Gray, 2014).

The mixed method approach combines both qualitative and quantitative methods in a single study (Creswell et al, 2003). This approach has several advantages for example, it allows for multiple objectives to be met and for complex circumstances to be included within the research. Furthermore, the data can be gathered from different perspectives allowing for the triangulation of results and an in-depth analysis (Creswell et al 2003., Kumar, 2014).

4.3 Methods Used in Previous Research

It is important when conducting research that the most suitable research method is selected. As identified through the literature review chapters, there are several areas which require further investigation including exposure to traffic related air pollution, public awareness and knowledge of air pollution and the current system used to manage air pollution levels. To gain an understanding of the methods most frequently used in the field of air quality, a systematic literature search was completed to identify the methods used in previous studies. A bibliographic

database (Science Direct) was used to conduct a search for relevant previous studies. The following key words were used to search the database; 'air pollution', 'traffic', 'health', 'awareness', 'knowledge', 'AQMA' and 'management'. The results from the search are presented in the tables including a brief description of the methods used.

The results are divided into 3 sections including:

- Methods used to measure levels of traffic related air pollution,
- Methods used to assess the participants' awareness of air pollution and knowledge of the health impact
- Methods used to evaluate air quality management

4.3.1. Methods used in previous research to measure the level of traffic related air pollution

The methods used previous research published on exposure to traffic related air pollution can be classified into three sections. This includes; using models to estimate levels of exposure, using existing data sets and monitoring the levels of exposure. **Tables 7-9** explore the previous research using these three methods. Due to the number of studies which have previously investigated the impact of air pollution, the search was limited to those published post 2010.

Table 7: Modelling Techniques

Author & Date	**Focus of Study**	**Study Location**	**Procedure**
Kim et al, 2014	Traffic related air pollution and Airway Hyper-responsiveness	Korea	Logistic Regression Modelling used. Health data collected via a questionnaire. Distance from the road used as a marker.
Li et al, 2015	Short term exposure to air pollution and effect on CHD	China	Mortality and air quality data from existing sources. Generalised Additive Models (GAM) used for investigate the impact of air pollution levels.
Zijiema et al, 2015	Depression and exposure to air pollution	Netherlands Germany Finland Norway	Land Use Regression Models used to estimated nitrogen dioxide exposure

Eze et al, 2014	Long term exposure to air pollution and diabetes	Switzerland	6392 participants Estimated average PM_{10} and NO_2 levels over 10yrs. Association of levels with diabetes investigated using mixed logistic regression models
Taj et al 2016	Air Pollution and number of healthcare visits	Sweden	Healthcare data obtained from a regional database and air pollution data from 6 urban background stations. Non-linear model used for analysis.
Bentayeb et al 2015	Long term exposure to air pollution and mortality	France	Exposure assessed using a chemistry transport model based on post code. Postal questionnaire used for demographic information.
Capraz et al, 2016	Air Pollution and Mortality	Istanbul	Data Analysed using Poisson Regression in a generalised linear model. Health and air quality data obtained from existing data sets.
Fecht et al 2015	Air Pollution and socio economic characteristics	England and Netherlands	Air Pollution maps were modelled using land use regression. Income from the multiple deprivation index was used.
Rodriguez et al, 2016	Air pollution and Urban Structures	Throughout Europe	Pollution levels from AirBase database. Analysis using Bayesian Model.
Duque et al, 2016	Strategies to reduce urban air pollution	Portugal	Stimulated the year 2012 using a numerical modelling tool.
Bertin et al, 2015	Foetal growth and exposure to air pollution	France	Nitrogen dioxide levels were estimated at mothers' homes using a land regression model. Foetal growth was assessed through birth weight.

Haddad et al, 2012	Respiratory Health and Air Pollution	Canada	Longitudinal cohort study with 598 participants. Response surface model used to estimate levels of nitrogen dioxide. Questionnaire used to collect health data.
Tong et al, 2016	Quantifying the impact of TRAP on indoor air quality	Boston	A CFD based air quality model was used to quantify the impact of o TRAP on indoor air quality.
Shekarrixford et al, 2016	Individual exposure to TRAP	Canada	NOx emissions estimated using a transportation and emissions model. Individual exposure was estimated using land use regression models.
Carugno et al, 2016	Hospitalisations in a high pollution areas	Italy	18 highly polluted and population dense areas were chosen. Poisson regression model used to determine are specific effect estimates.
Halonen et al, 2016	Long term exposure to TRAP and hospital emissions	London	Existing data on hospital admissions was used. For exposure the Kings College London dispersion model was used to estimate annual average concentrations.
Halonen et al, 2016	Long term exposure and mortality	London	Poisson Regression models used to investigate.

Modelling is a common method of estimating air pollution levels in recent research. There are various different types of models such as dispersion models and land use regression models. Modelling is used by DEFRA to assess their compliance with European objective levels (DEFRA, 2010). The reliability of models in predicting air pollution levels have been questioned. Section 4.4.2 discusses the current advantages and disadvantages of modelling.

Table 8: Existing Data Sets

Author & Date	**Focus of Study**	**Study Location**	**Procedure**
Namdeo et al, 2011	Estimation of age related vulnerability to air pollution	Leeds, UK	Existing data sets used for air pollution levels, meteorology & health. 5 years of data included.
Chen et al, 2016	Air pollution and its effects on fasting blood glucose	China	Longitudinal study which included air pollution data and meteorology data from the Environmental Monitoring centre. Questionnaires to collect health data and blood samples.
Gatto et al, 2014	Air Pollution and cognitive function among middle aged adults	Los Angeles	Annual average concentrations used from US environmental protection agency. GIS used to map levels with address. 1495 participants. Cognitive tests completed and a demographic questionnaire.
Gora et al, 2013	Developing an Air Quality Index	India	Air pollution data from West Bengal Pollution Central Board was used
Chen et al, 2016	Exposure to urban air pollution and lung cancer	China	Air Pollution data acquired from local environmental monitoring centre
Woodward et al, 2016	Minimizing air pollution exposure	Los Angeles	Data from public databases used including; traffic counts, addresses for care facilities and air pollution levels

Existing data sets have been used for air pollution levels, meteorology, traffic levels and health impact. Studies such as Chen et al (2016) and Gatto et al (2014) have used existing data sets for the air quality levels and combined it with their own health data. The majority of studies have retrieved the information from government sources.

Combining two data sets such as air pollution levels and health does not consider other confounding factors. The use of existing data sets is discussed in **Section 4.4.3**.

Table 9: Monitoring Air Pollution Levels

Author & Date	**Focus of Study**	**Study Location**	**Procedure**
Tabaku et al, 2011	Air Pollution and Children's Pulmonary Health	Albania	Measured levels of PM, NOx, & 0_3 at 5 stationary points across the city. 238 urban questionnaires completed and 72 suburban to gain information on health.
Gallagher et al, 2013	Air Pollution in Dublin	Dublin	$N0_2$ measured using chemilumescent analyser. Traffic data from Dublin City Council. Wind speed and direction measured using an anemometer. CFD model also used.
Karakatsani et al, 2010	Ambient air pollution & respiratory health among mail carriers	Greece	41 mail carriers wore passive samplers to measure $N0_2$ &0_3. Participants completed a self-administered questionnaire on health and demographics.
Villeneuve et al, 2012	Ambient air pollution & Stroke	Canada	Five fixed monitoring stations and meteorological data.
Obara et al, 2011	Impact of vehicle traffic on rural air quality	West Midlands, United Kingdom	4 monitoring locations. Traffic levels counted for 1hr between 8-10am over 22 month monitoring campaign. PM measured P Trak Ultrafine Particle Counter. Considered impact of vegetation & meteorological data.

Liu et al, 2015	Commuting mode & exposure to air pollution	Taiwan	120 university students involved in the research. 1hr continuous measurements of PM_{10} were conducted using a Dust Portable monitor. Models used to investigate impact.
McAdam et al, 2011	Proximity to road and air pollution levels.	Canada	Measured using 2 portable air samplers. Measurement of $S0_2$, 0_3, NO, NO_2, NOx, $PM_{2.5}$ were recorded at 3 distances- ground level, 30m, 60m for 14 days.
Beelen et al, 2013	Development of Land Regression Models	Europe	N0x and NO2 measured using passive samplers at 40 sites in 36 areas. Spatial variation explained through LUR modelling.
Boogaard, 2012	Impact of traffic policies on air pollution concentrations	Netherlands	Measurements of PM_{10}, $PM_{2.5}$, N0x, $N0_2$ at 18 locations within an LEZ. 2 sampling periods of 6 months were completed. Automated traffic counts completed for 1 week.
Skene at al, 2010	Traffic and landscape effects of N02 levels	America	$N0_2$ levels were sampled outside 985 properties for 4 months (1 each season) using Palmes Diffusion Tubes left in place for 1 month.
Liu et al, 2012	Long Term exposure to air pollution	Switzerland	Passive $N0_2$ measurements were taken outside 100 residences in 3 seasons. Regression model then developed.
Bossche et al, 2016	Air Pollution Monitoring	Antwerp, Belgium	393 measurements of black carbon using ViTO airQmap. City wardens carried equipment while on duty.

Schembori et al, 2013	Personal, indoor and outdoor levels among pregnant women	Barcelona	54 pregnant women wore personal passive badges to measure $N0_2$ for 1 week. Levels were also simultaneously measured at their homes. Time activity diaries were completed and house characteristics were recorded.

There are various methods used to monitor air pollution levels in the studies included reviewed in this section. There are studies which use centralised automatic monitoring stations. These stations are used to give the levels for a whole area. There are also studies which have used passive diffusion tubes which allow for tubes to be placed at the residents' homes. These two methods both have advantages and disadvantages which are discussed in **Section 4.4.1**.

4.3.2. Methods used to collect information on perception and awareness of air pollution

Table 10 provides an overview of the methods used in previous research to understand the public's awareness and knowledge of air pollution.

All other method searches were completed using studies post 2010 due to the vast amount of available literature on air pollution. In relation to awareness and perception of air pollution the number of recent studies is low therefore the search included studies conducted from 1990's.

Table 10: Previous Methods used to assess public awareness of air pollution

Author and Date	**Focus of Study**	**Study Location**	**Procedure**
Bickerstaff and Walker, 2001	Public knowledge and understanding of air pollution and environmental risk	Birmingham	378 survey responses and 50 interviews
Brody et al, 2004	Perception of air quality in conjunction with spatial analysis	Texas	870 phone interviews completed. Multivariate regression modelling also used.

Bush et al, 2001	Perception of air pollution and health	North East England	Postal questionnaire and interviews
Day, 2007	Perceived health risk of traffic related air pollution	London	Interviews and surveys
Deguen et al, 2008	Risk perception of air pollution	France	Phone questionnaire
Elliott et al, 1999	Proximity to industrial air pollution and risk perception	Canada	Community survey with 402 responses
Lercher et al, 1995	Perceived air pollution level and behaviour	Austria	Survey
Simone et al, 2012	Concern about air pollution	Canada	1002 phone surveys completed across three locations
Smallbone, 2010	Interpretation of air quality information. Participants in the research had respiratory illnesses	United Kingdom	Focus group, workshop and survey

There is a lower number of available studies on public perception and knowledge of air pollution. The review of methods indicates that questionnaires or interviews are the most common method of gathering empirical data. Questionnaires have gained a higher number of responses while interviews have a lower response rate but may gain greater depth. The advantages and disadvantages of both these methods are discussed in greater detail in Sections 4.4.4 and 4.4.5.

4.3.3. Methods used to evaluate air quality management

Table 5 summarises the previous research methods used to assess the current local air quality management.

Table 11: Previous methods used to review LAQM

Author & Date	**Focus of Study**	**Study Location**	**Procedure**
Brunt et al, 2016	The consideration of public health in Local Air Quality Management	England	Review of current literature
Longhurst et al, 2016	Progress in air quality management	England	Review
Barnes et al, 2015	Has local air quality been improved by the local government?	Bristol	Focused on 1 local authority and reviewed whether the action plan had caused a reduction in N02. Desk based research.
Barnes et al, 2012	Air Quality Action Planning	United Kingdom	Questionnaire survey of local authorities on behalf of DEFRA. 55% response rate (239 of 433 local authorities)
Olowoporoku et al 2012	Integrating transport planning and local air quality management	England	Systematic review of documents Web based questionnaire Case study interviews 142 local authorities participated (44% of total number)
Jones et al, 2010	Managing air pollution at local level	England	Semi structured interviews with environmental health officers, land use planning officers and transport planners. 12 interviews.
Olowoporoku et al 2010	Longitudional study focusing on the integration between LAQM and transport planning	England	9 local authorities chosen for a document review
Longhurst et al 2010	The future of Local Air Quality Management	England	Review of current literature

The review of existing research of Local Air Quality Management identified a range of methods used. In this area of research there are a number of studies that have

completed a document analysis. This involves the collection of action plans and other associated documentation and evaluating if the plans have been actioned. This method is successful in identifying whether documented air quality plans have been actioned. However, it fails to consider the human side and identify the reasons for some of the plans not being implemented. Other studies have included the use of questionnaires or interviews to investigate the reasoning for the success or failure in the implementation of the action plans. A questionnaire was used in one of the studies to maintain the anonymity of participants (Olowoporoku et al 2012). The use of questionnaires and interviews as a data collection tool are discussed in **Section 4.4**.

4.4 Review of Data Collection Methods

4.4.1 Monitoring

The reference method for monitoring Nitrogen Dioxide levels is using an automatic chemiluminescence analyser. This analyser provides high resolution data however to ensure the data is reliable to the machine must been maintained to a high standard. Regular calibration is required and the analyser should only be used by a trained professional. The analyser is an expensive method of monitoring nitrogen dioxide levels (DEFRA, 2015). In previous research (Tabaku et al, 2011., Gallagher et al, 2013., Villeneuvue et al, 2012), existing analysers have been used to obtain levels of nitrogen dioxide. The analysers are large and one is often placed to cover a wide area. This does not allow for spatial variations in air pollution to be considered.

Diffusion tubes are small, unobtrusive and a low-cost method of monitoring nitrogen dioxide levels. These characteristics make diffusion tubes a useful method of monitoring levels at multiple sites over various locations. The monitors do not require an electrical supply and are silent therefore causing little interference to participant's daily life (Nash and Lieth, 2010). In addition, diffusion tubes are simple to use and do not require calibration or maintenance by trained professional (Tang et al, 2001). Although diffusion tubes have many advantages, there is a greater uncertainty compared to the results from an automatic analyser. The accuracy is currently estimated to be +/- 20% compared to +/- 10 % for automatic analysers. This

difference in accuracy can be compensated by the number of tubes which can be placed in an area and their ability to be placed easily on the façade of a building. The greater number of tubes, the greater ability to measure the spatial variability of air pollutants. The precision of the tubes can be increased by co-locating diffusion tubes with an automatic analyser. In addition, selecting a laboratory to prepare and analyse the results which has achieved a satisfactory rating in the AIR Scheme (previously WASP) which ensures the laboratory chosen follows current guidance and prepares the diffusion tubes accurately to minimise error (DEFRA, 2016).

4.4.2 Modelling

Modelling is a frequently used method to estimate the levels of air pollution. All the studies mentioned in Table 7 have used models to predict the levels. There are various different types of models including proximity models, dispersion models and land use regression models. The reliability of models often depends on the accuracy of the information which is input (HEI, 2010). All models have advantages and disadvantages. Some of the commonly used models are discussed below;

- Proximity Models

  This exposure model can easily be applied and used to estimated air pollution levels. It has been c criticised for not including factors which affect air pollution. For example, the model does not consider the impact of meteorology on dispersion or confounding factors such as socio- economic status (HEI, 2010).

- Geostatistical Models

  This model is reliable when it is used in conjunction with a dense monitoring network. A large amount of measurements are required and this is often not achievable for smaller research projects (HEI, 2010).

- Land Use Regression Models

  This model is commonly used in air pollution research. The model takes into consideration other factors in the area which allows for the variability in levels

to be explained. The model takes the measured concentrations of air pollution levels, land use information, traffic levels, demographic and geographic factors to predict the levels of air pollution (Habermann et al, 2015).

- Dispersion Models

  Dispersion models involves the input of a large amount of data. The following data incorporated; air quality, car emission and meteorological data. The reliability of the model is dependent upon the assumptions made and validity of the input information. The Health Effects Institute (2010) have described the model as 'data and computation intensive'

- Hybrid Models

  Hybrid models have been described as providing the 'best' estimate. The model combines measurements of personal exposure or time activity data with exposure models (HEI, 2010).

- Pollution Climate Mapping (PCM)

  This is a GIS based, semi empirical model. This model is used by DEFRA to collate air pollution levels across the UK and assess compliance with EU objective levels. It is calibrated annually using measured levels. There is uncertainty in relation to the models accuracy at predicting future levels (DEFRA, 2012).

Models are often used due to the expense associated with monitoring equipment and to provide a wider picture of overall air pollution levels across a country (Williams et al, 2011). The Health Effects Institute (2010) have stated that proximity models are the least reliable as they do not consider confounding factors. Models have been developed recently which are more reliable especially those which are validated using real world data. The measurement of air pollution levels alongside the model has been identified as critical to increase the reliability (HEI, 2010). DEFRA (2010)

have reviewed the effectiveness of models in the prediction of air pollution levels and their requirement for policy decisions. They acknowledged that models contain 'assumptions and simplifications' which can lead to difficulties. The National Research Council (2007) stated that models are always incomplete but making them more complex leads to problems. Williams et al (2011) found that the same model implemented by different organisations produced different results. This finding questions the reliability of models in determining air pollution levels. The effectiveness of modelling the levels of air pollution is dependent upon the model being used. The Health Effects Institute (2010) recommend that if models are being used a 'hybrid' model which measures personal exposure provides the 'best estimate'. The hybrid model involves the measurement of air pollution levels which are then input to the model. The effectiveness of this would depend on the type of monitoring equipment used and the number of measurements.

4.4.3 Existing Data Sets

The review of previous methodological approaches identified several studies which use existing data sets. The source of the data set varies between each study for example it maybe from a government department or from a previous research project. The existing data sets included information air pollution levels (Li et al, 2015., Capraz et al, 2016., Rodriguez et al, 2016., Namdeo et al, 2016., Chen et al, 2016), meteorological levels (Namdeo et al, 2011., Chen et al, 2016) and health information (Li et al, 2015., Jai et al, 2016., Capraz et al, 2016., Halanen et al, 2016., Namdeo et al, 2011). Existing data sets are often used in conjunction with the monitoring of air pollution or use of questionnaires to gather data. Data sets are useful for when the measurement of traffic levels or weather conditions cannot be completed. The use of existing data sets for estimating personal exposure to air pollution does not take into consideration the variability of air pollution levels.

4.4.4 Interviews

There are several studies which have used interviews to gather both data on public perception of air pollution (Bickerstaff and Walker, 2001., Brody et al, 2004., Day et al, 2007) and to gain views of professionals on the management of air pollution (Jones et al, 2010., Olowoporoku et al, 2012). Interviews are useful to gain more

detailed information and are often used to gather data on complex situations (Rugg and Petre, 2007., Gray,2014., Kumar,2014). The questions can also be explained if the participant does not understand and can be adapted depending on the participants' response (Robson and McCarton, 2016., Kumar,2014). Interviews are often used to explore attitudes and feelings towards an issue and often participants feel more confident to verbally share details (Gray,2014). The quality of information gained from interviews is dependent on the quality of the interviewer and their interaction with the participant. A rapport must be built with the participant to gain trust and respect (Gray,2014). Furthermore, interviews are a time consuming and expensive method for gathering data (Denscombe, 2010).

4.4.5 Questionnaires

Questionnaires have been used in several studies (Lercher et al, 1995., Elliott et al, 1999., Bickerstaff and Walker, 2001., Bush et al, 2001., Deguen et al, 2008., Barnes et al, 2010., Tabaku et al, 2011., Simone et al, 2012., Haddad et al, 2012., Karkatsani et al, 2012., Kim et al, 2014., Gatto et al, 2014., Bentayeb et al, 2015., Chen et al, 2016) to gather data on public perception of air pollution and health. It is a useful method of gaining information on trends of a large population (Creswell, 2007., Gray, 2014). Questionnaires are often a more time efficient method of gathering data and closed questions are easily coded for data analysis (Gray,2014). However, questionnaires can have a low response rate, with Rugg and Petre (2007) stating a researcher cold calling may have a response rate of 10%. This then leads to a section of the population who are unrepresented creating bias (Rugg and Petre, 2007). A questionnaire must be kept short or the response rate will be affected. The questions must be easy to understand (Kumar, 2014).

4.4.6 Mixed Method Approach

The mixed method approach has been used in previous research in the field of air pollution to combine the collection of quantitative air quality data and qualitative health or management data (Karakatsani et al, 2010., Schembori et al, 2013). The use of mixed method allows for complex situations to be investigated and for multiple objectives to be met which can extend the range of the research (Walliman,2011., Gray, 2014). In addition, the weaknesses of one method can be

compensated by the strengths of the second method (Creswell, 2007., Denscombe, 2010). However, this method can be time consuming if it involves contacting two study populations and additional analysis skills (Walliman, 2011).

After reviewing and evaluating the methods used in previous research the most appropriate methods were chosen.

4.5 Research Design

Chapter 1 stated the aims and objectives of this research. Objective 1 was met through the critical review of the current evidence on the health impact of air pollution. This section of the methodology states how the research is designed to meet the following objectives;

Objective 2 – To establish the knowledge and awareness of air pollution of residents living within Air Quality Management Areas

Objective 3- To establish the current levels of nitrogen dioxide, indoor and outdoor, on several roads in Northern Ireland

Objective 4 – To review the Local Air Quality Management (LAQM) Regime and highlight the importance of air quality to policy makers

To achieve the objectives, the most appropriate approach was a mixed method design. This allowed for both qualitative and quantitative data to be collected.

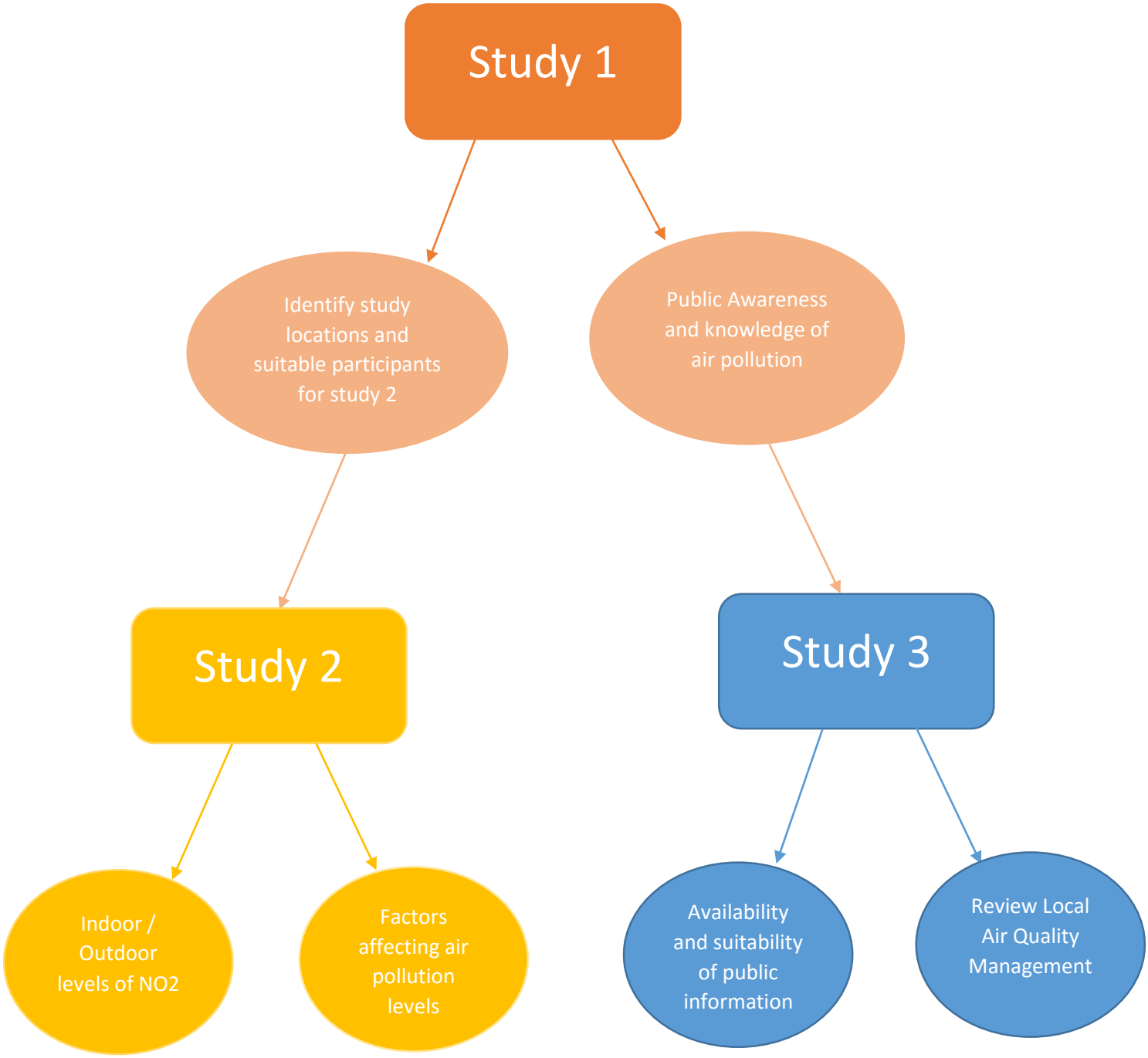
4.5.1. Conceptual Framework

The conceptual framework (**Figure 4**) provides an overview of the research design. The framework illustrates how the three different studies in the research link to achieve the overall aim. The framework was used throughout the research design, data collection and data analysis stages to ensure continuity.

The framework illustrates the link between all three studies. Study 1 identifies suitable study locations which meet the selection criteria. In addition, it identifies residents in each of the areas who a willing to participate in an additional study. These two aspects are brought forward and applied in study 2. Study 1 also aims to identify the awareness and knowledge of residents about air pollution in their area.

The results from this study informed the focus of Study 3. Further detail on the aims and structure of each study can be seen in **Figures 5, 6 & 7.**

Figure 4: Conceptual Framework



Study 1 was designed to meet objective 2 which states: To establish the knowledge and awareness of air pollution of residents living within Air Quality Management Areas

Figure 5: Study 1

Study 1- Knowledge and Awareness of Air Pollution			
a) **Identify locations which meet the inclusion criteria**	b) Identify the participants awareness and knowledge of air pollution using a questionnaire	c) Identify time activity pattern and indoor sources of nitrogen dioxide	d) Identify residents willingness to participate in study 2

Study 2 was designed to meet objective 3 which states: To establish the current levels of traffic related air pollution, indoor and outdoor, on several roads in Northern Ireland

Figure 6: Study 2

Study 2 - Establish the current level of traffic related air pollution		
a) **Measure nitrogen dioxide levels indoor and outdoor in several locations**	b) Identify the impact of several factors on air pollution levels for example distance and season	c) Measure personal exposure to nitrogen dioxide

Study 3 was designed to meet Objective 4 which states: To review the Local Air Quality Management (LAQM) Regime and highlight the importance of air quality to policy makers

Figure 7: Study 3

Study 3 Review Local Air Quality Management		
a) **Establish the views of professionals on the effectiveness of Local Air Quality Management**	b) Interview residents on their awareness of information available on air pollution	c) Recommend further action to improve local air quality

Each study is discussed in depth in the following Section: **4.6, 4.7** and **4.8**. Each section will include details on: the research method, selection criteria, sampling procedure, piloting, data collection and data analysis.

4.6 Study 1

Study 1 was designed to meet Objective 2 which states;

To establish the knowledge and awareness of air pollution of residents living within Air Quality Management Areas.

To achieve this the following steps are required from Study 1:

- Identify suitable study locations
- Establish the participants' awareness and knowledge of air pollution
- Ascertain the health status of the participants
- Identify suitable participants for Study

4.6.1. Method

After reviewing previous research and considering factors such as data analysis and response rates the most appropriate method to collect the data required for Study 1 was a questionnaire. A questionnaire has been used in many previous studies to

collect both information on air pollution perception and health information (Lercher et al, 1995., Elliott et al, 1999., Bickerstaff and Walker, 2001., Bush et al, 2001., Deguen et al, 2008., Barnes et al, 2010., Tabaku et al, 2011., Haddad et al, 2012., Karkatsani et al, 2012., Simone et al, 2012., Kim et al, 2014., Gatto et al, 2014., Bentayeb et al, 2015., Chen et al, 2016). Questionnaires are also a time efficient and cost efficient method of data collection. The questionnaire can be seen in Appendix 1.

The questionnaire has three sections. The first section is designed to collect general information about the household including; the number of people who live at the property, the type of heating, number of smokers and number of hours spent at the property. This information was collected to identify potential confounding factors for health problems. In addition, the information was useful for identifying suitable participants for Study 2 which required non-smokers.

The second section focuses on the participants' awareness and knowledge of air pollution in their area. One of the questions assesses their awareness of the health impact of exposure to traffic related air pollution. The health conditions included were those through the literature review were found to have the most consistent scientific evidence. There are several types of questions used in this section including likert scales and requiring participants to rank responses. Likert scales are used to measure participants' attitudes and feelings. Likert Scales are simple to develop and are easily completed by the respondent. The most common scale used is a 5 point likert scale with strongly agree and strongly disagree at each end (Bertram, 2008).

The third section investigates the health status of those living at the property. A table was considered the most appropriate method of recording this data. The health conditions asked were again those most consistently reported in previous literature. The table also asked participants to record their age, the number of years they have had the health problem and if they noticed any improvement or worsening of their condition since living at the property.

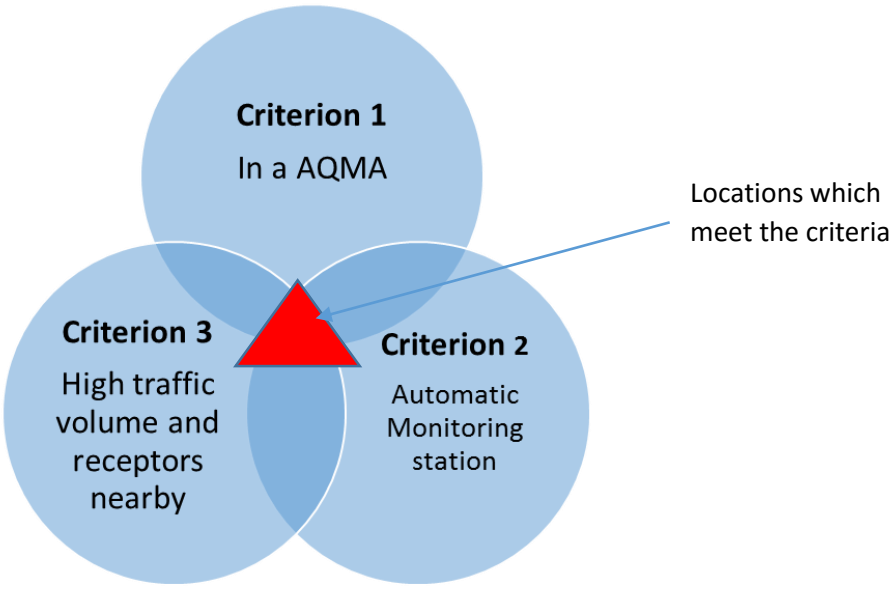
The questionnaire was 4 pages in length to encourage participation. A questionnaire which is long in length can lead to a reduction in the response rate when sampling

the general public. If the questionnaire takes a long time to complete participants can become fatigued and not consider the answer to questions carefully (Meadows, 2003).

4.6.2 Study Location Selection

To identify suitable study locations, an inclusion and exclusion criteria was created. In Northern Ireland, areas which exceed the air quality objectives set out in legislation must be declared as an Air Quality Management Area (AQMA) and the reason for the exceedance must be stated. For an area to meet the inclusion criteria for this study it should be within an AQMA declared for traffic. Furthermore, the area should have an air quality monitoring station. Co-location of diffusion tubes at a property close to the automatic analyser allows for the accuracy of the diffusion tube results to be verified. In addition, in certain locations the level of particulate matter from automatic stations can also be recorded. The study areas must be located within a residential housing area to identify the potential impact on residents. For the study areas to be comparable the roads should have a similar traffic volume and speed. The selection criteria is summarised in **Figure 8**.

Figure 8: Study Location Selection Criteria



The study locations which met all the criteria are listed below with a brief description of the area.

- **Lonsdale Road, Armagh**

  The AQMA includes Railway Street, Lonsdale Road, Mall West and Barrack Street. The boundary is set 20 metres from the centre line of the road. These streets are the main commuting routes to Portadown, Newry, Monaghan and Dungannon. On average 10,240 cars travel on these roads each day.

Figure 9: Lonsdale Road, Armagh

- **Ormeau Road, Belfast**

  This AQMA encompasses the Ormeau Road from the junction with Donegall Pass to the City boundary at Galwally. On average 25,200 cars travel on the road each day.

Figure 10: Ormeau Road, Belfast

- **M1 Westlink Corridor, Belfast**

  This AQMA runs from the Belfast City Boundary at Sir Thomas and Lady Dixon Park to the end of the Westlink at Great Georges Street and York Street. Stockmans Lane and Kennedy way are included. The M1 is the longest motorway in Northern Ireland and connecting commuters from the West to Belfast and Belfast to Antrim. The M1 has an average of 89,960 cars per day. In addition, Stockmans Lane has an average of 32,840 cars per day.

Figure 11: M1 Westlink Corridor

- **Upper Newtownards Road, Belfast**

  The AQMA on the Upper Newtownards Road runs from the North Road junction to the Belfast City boundary at Hawthornden Way. On average 16,620 cars travel on the road each day.

Figure 12: Upper Newtownards Road, Belfast

- **Dales Corner, Londenderry**

  This AQMA encompasses Ebrington Terrace, Columba Terrace and Glendermott Road. The AQMA has a large junction with traffic lights, at rush hour the traffic lights cause tail backs and long idling periods for vehicles.

Figure 13: Dales Corner, Londonderry

- **Main Street, Dungiven**

  Dungiven Main Street is the main arteriole route between Belfast and Londonderry. It is used frequently as a haulage route for the North West of Ireland to the ports of Belfast and Larne. On average 14,590 cars travel through the village on a daily basis.

Figure 14: Main Street, Dungiven

- **Newry Urban Centre**

  Newry City is located within the valley of a basin which can inhibit the dispersion of pollutants. 5 Air Quality Management Areas were revoked to form 1 large AQMA encompassing all the main commuter routes. The roads with the most congestion and previous AQMAs include Canal Street, Water Street, Kilmorey Street and Sandy Street. The automatic monitoring station is currently located on Canal Street. Canal Street has 3 storey buildings on each side of the street which creates canyon effect. On average 17,250 vehicle travel on the street each day. Canal Street currently has the highest recorded levels of air pollution in Newry City. Canal Street has a weight restriction to reduce the number of HGV vehicles travelling on the road.

Figure 15: Newry Urban Centre

- **Antrim Road, Glengormley**

  This AQMA is used by many to commute and there are several schools within a short distance of its boundaries. On average 11,500 vehicles travel on the road each day. The area has residential properties on both sides of the road and is between two sets of traffic lights causing cars to start and stop.

Figure 16: Antrim Road, Glengormley

Once the locations which met the selection criteria where identified, the residential properties in each area were identified. The process involved obtaining maps of the AQMAs from the local council action plans. The air quality management areas in Armagh, Ormeau Road, Upper Newtownards Road, Dales Corner, Dungiven and Glengormley are 1 street therefore the number and location of the houses were easily identified. The air quality management area in Newry and the M1 Westlink Corridor are larger therefore GIS software was used to identify residential properties.

One of the aims of the questionnaire in Study 1 was identify suitable residents for participation in Study 2 which involved the monitoring of nitrogen dioxide. To increase the reliability of the monitoring results, monitoring was only completed in locations with an automatic monitor. On reflection, the questionnaires could have been completed in all locations but due to time constraints this was not included within this research. Extending the questionnaire to all locations is an area of future research.

4.6.3. Sampling Procedure

Probability and non-probability sampling are the two key approaches used to sample a chosen population. Probability sampling gives each member of the population an equal chance of selection and is the most reliable method of choosing a random sample (Creswell,2007., Kumar,2014). Achieving probability sampling is not always practically possible therefore non probability sampling is often used. There are several types of non -probability sampling including, Quota sampling, criterion sampling, opportunistic, snowball and expert sampling (Gray,2014., Kumar,2014).

For Study 1 the most appropriate method of sampling the population was criterion sampling. Criterion sampling involves selecting cases that meet pre- determined criteria (Kumar, 2014). Within this research the criteria for inclusion was: the study population had to live within the boundaries air quality management area which had an automatic monitoring station. This method is often used to identify the most useful participants for the research. Residents within air quality management areas are the people who are potentially exposed to the highest levels of traffic related air pollution therefore are considered the population which should be sampled within this research.

4.6.4. Questionnaire Administration

Questionnaires can be administered in two ways; self-administered and interview administered. Self-administered questionnaires are posted, emailed or completed online. This method provides greater confidentiality and is especially useful when questionnaires are addressing sensitive issues. Furthermore, the questionnaire can be completed at time convenient to the respondent (Leung, 2001).

Interview administered questionnaires are completed face to face or over the phone. This method allows for questions to be explained in greater detail to the respondent and allows for those who are illiterate to be involved (Leung, 2001). In addition, allows for more detailed information to be collected from the respondents however it is often considered to be a more expensive method of collecting data (Meadows, 2003).

The method chosen was an interview based questionnaire. To gain a representative sample of the population, the researcher visited each area during the day, the evening and at the weekend. This method was chosen for the researcher to identify suitable participants for Study 2 and to encourage participation for the next study by explaining what would be involved.

4.6.5. Pilot Study

The first step in piloting the questionnaires involved distributing the questionnaire to a small group of academics. This identified some changes to be made to the structure of the questionnaire and the wording of several questions. Data collection began in the Air Quality Management Area with the smallest population which was the Antrim

Road in Glengormley. This allowed the questionnaire to be piloted using research participants. The participants understood the questions however the information gained from some questions did not have the level of detail expected. After reviewing the questions, it was decided to insert additional questions to gain a more detailed response. Additional questions allowed information to be gathered on the residents' awareness and knowledge of air pollution.

4.6.6. Data Analysis

The questionnaires collected quantitative data and the results obtained were analysed using SPSS (Statistical Package for Social Sciences). SPSS allows for complex statistical analysis to be completed using a variety of statistical tests (Hinton et al, 2014). When designing the questionnaire, data analysis was considered. The questionnaire included nominal, ordinal and interval data. Each questionnaire was given a unique number which would allow for the study location to be identified and a questionnaire to be obtained in case data entry mistakes were found.

Before analysis was conducted the data entered was checked for errors. There are several methods for completing this task depending on the variable. For categorical variables such as gender, a descriptive test was run. The minimum and maximum values were checked to ensure all values were within the appropriate range. For example, gender should only have 1 or 2 for male and female. The number of missing cases was also checked. If a large number of missing cases was returned, reasons for this was checked for example if data has been entered into the wrong column. Similar tests were used for continuous variables. Completing descriptive statistics allowed for the minimum and maximum values to be checked. The mean score was also checked to ensure there was no anomalies. The majority of the data set included categorical variables therefore data entry mistakes were easier to be identified using the descriptive statistics. Any mistakes found were corrected before data analysis was started.

To begin analysis, descriptive statistics were used to summarise the data collected. Descriptive statistics provide an overview of the data collected by illustrating the

characteristics of the sample and how the data is distributed (Davis, 2013). Mean, mode and median were used and data was displayed in bar graphs and pie charts which are included in **Chapter 5**. Crosstabulation was used to summarise data between variables. For example, it was used to compare the study location with the number of participants who stated they had asthma.

Parametric tests use the information collected from the sample population to estimate the population values (Hinton et al, 2014). All parametric tests assume that the data is from a normally distributed population (Hinton et al, 2014) therefore before beginning the analysis the data was plotted on a histogram to check the data followed a normal curve.

There were several different inferential tests used depending on the type of data. To determine if a correlation existed between two variables Pearson Chi Squared Correlation Coefficient was used (Denscombe, 2009). One example of when Pearson Chi Square was used within the research was to identify the impact of exposure to nitrogen dioxide and on the number of illnesses which a person had. To compare the means of variables Analysis of the Variance (ANOVA) was computed. ANOVA was used to identify the relationship between three or more variables (Davis, 2010). For example, ANOVA was used to identify the relationship between the location where a person lived and the number of health conditions they had. An Independent T-Test was used to identify if two groups were statistically different (Denscombe, 2010). For example, this test was used when identifying the impact of gender on the number of health conditions a person had.

Spearman correlation was also computed in SPSS. Spearman correlation is a non-parametric test which is used for investigating the relationship between ordinal data (Hinton et al, 2014). For example, this test was used to investigate the respondents rating of air pollution and how they rated their concern about air pollution.

For all tests conducted, statistical significance was considered at least 95% confidence level ($p < 0.005$). Within the results in **Chapter 5**, the p value is given for each test as an indication of the level of significance.

The respondents were asked to select their top three concerns in their area. To analyse the responses, an overall score for each concern was calculated. A rating of 3 indicated it was the participant's highest concern and a rating of 1 indicated it was their lowest concern. The overall concern was calculated by multiplying each rating by the number of participants who selected it. A total was then calculated for each concern. Calculating the overall score gives an indication of the concerns most frequently identified by the participants and also considered the rating of their concern.

4.7 Study 2

Study 2 was designed to achieve the following objective; 'To establish the current levels of traffic related air pollution, indoor and outdoor, on several roads in Northern Ireland.' To achieve this the following are required:

- Identify suitable participants from Study 1
- Choose a suitable method to monitor nitrogen dioxide indoor and outdoor
- Complete monitoring in all location identified in Study 1

4.7.1. Method

The following inclusion and exclusion criteria was set for study 2. The participant must have completed the questionnaire in Study 1 (and therefore live within an AQMA), there must be no smokers living at the property and the property should be within 200 metres of an automatic monitoring station. All participants who met the criteria were asked to participate in study 2 after completing the questionnaire.

Nitrogen dioxide is one of the main pollutants emitted from traffic and is often used as a marker for traffic in research therefore it was chosen as the most appropriate pollutant to measure for this study. The Health Effects Institute (2010) stated that nitrogen dioxide is a suitable marker for the complex mixture of pollutants emitted from traffic. The most appropriate method of measuring the indoor and outdoor

levels of nitrogen dioxide was via a diffusion tube. Diffusion tubes were chosen as they are unobtrusive for placing outside and inside the participants' home, they do not require electricity and are inexpensive which would allow for all houses to be monitored at the same time.

Particulate matter is another pollutant from traffic. A reliable and low- cost particulate matter monitor which would measure indoor and outdoor levels could not be obtained. Therefore, measurements of PM_{10} from automatic monitoring stations in the AQMAs were to be recorded during the monitoring period. It was therefore necessary for houses participating the study to be within 200 metres of an automatic monitoring station for the results to be representative of their property. The Health Effects Institute (2010) state the decay distance if traffic related air pollution to be 200 metres from the source. This is also confirmed by Gilbert et al (2003) which is used as a reference in the World Health Organisation REVIAPP document as stating that the greatest decrease in air pollution levels occurs within the first 200 metres.

The literature review identified that there are various factors which can influence air pollution levels. It was evident that these factors would need to be considered when completing Study 2. As nitrogen dioxide is known to show seasonal variations, it is recommended by DEFRA that monitoring is completed in both winter and summer (AEA Energy and Environment, 2008). To consider this, within Study 2 monitoring was conducted for 1 month in the winter and 1 month in the summer. January was chosen as the winter month as previous records have shown it is the month with the lowest temperature records. June was chosen for the summer month to avoid participant withdrawal due to holidays and due to other potential sources which could interfere with results in July.

Another factor which can influence exposure is distance from the road. The distance of the house façade to the roadside was measured using a Leica DISTO A3 laser distance meter. Other built environment factors were recorded such as if the property was located at traffic lights, if the property had greenery or large fences and the number of windows at the property and how often they are opened. All these

factors can influence indoor and outdoor levels of air pollution and account for the variation of levels in a street.

To give a deeper insight into individual exposure to nitrogen dioxide, residents were asked if they would like to further participate in the research by wearing a personal monitor for 1 week. Personal monitoring also involved recording a personal activity diary.

Air pollution modelling is defined as, 'a numerical tool used to describe the causal relationship between emissions, meteorology and other factors' (Daly and Zannett, 2007). In comparison, air pollution monitoring, 'collects quantitative data on the levels at the specific location at that time' (Daly and Zannett, 2007). Taking into consideration the definitions and the review of models in **Section 4.4.2**, it was decided not to complete air pollution modelling as part of this research. The monitoring was not the sole focus and was completed to provide an indicative level of nitrogen dioxide in each of the areas. Furthermore, modelling of air pollution levels in Northern Ireland is already currently available. To extend this research in the future, air pollution modelling could be included.

4.7.2 Pilot Study

Diffusion tubes were placed at two properties for 1 week as a pilot study. This study was completed to ensure the tubes would be suitable for measuring nitrogen both indoor and outdoor. It also allowed for the best method of attaching diffusion tubes to the property façade and indoor to be decided upon. As a result of the pilot, it was decided to attach outdoor diffusion tubes to a drainpipe using a holder and a cable tie. For the indoor tubes, an upstairs bedroom facing the road was decided to be the most appropriate location. This meant that other sources of nitrogen dioxide (such as cooker and boiler) within the property to be further from the monitor therefore minimising influencing the results. A holder was designed for the indoor diffusion tube. The holder was designed to be placed on top of an item of furniture in the bedroom.

4.7.3 Receiving, placing and removing diffusion tubes

The diffusion tubes are prepared by the laboratory. Two stainless steel grids are coated with absorbent (50% Triethanolamine, 50% Acetone) and placed inside the end cap. Each tube is then given a unique identification number and placed in an airtight bag.

To ensure the highest accuracy the following procedure was followed once the diffusion tubes were received. On receipt the diffusion tubes were checked to ensure that there were no breakages and that the correct number of tubes were contained. The tubes were kept in an air tight bag and stored in the fridge until required. When needed the tubes were taken to the location, the diffusion tube holder was attached to the façade of the property and the diffusion put in position and the cap removed. The holder allows the tube to be 5cm from any flat surface and all holders were placed at least 2.5m from the ground to avoid vandalism. The unique identification number for the tube was recorded on the exposure sheet, along with the date and time. The tubes were exposed for four weeks. Transport blanks were also taken when travelling with tubes. This increased the reliability of the results by showing if the tubes were contaminated during transport. On collection, the tubes were removed and checked to ensure there is no damage or water in the tube. The end cap was placed on the tube and it is put in an airtight bag. The date and time of removal was recorded on the exposure sheet. The tubes were sent back to the lab for analysis.

4.7.4 Data Analysis

Before deciding on a laboratory for supplying and analysing the diffusion tubes, the results of the AIR testing scheme was considered. The AIR scheme (previously known as WASP) is an independent testing scheme by Health and Safety Laboratory (HSL). Laboratories are sent diffusion tubes (test samples) each quarter, to analyse and their results are compared with the actual values. This test assesses the analytical performance of the laboratory. Laboratories considered for use within this research should have received a satisfactory performance in the previous year of testing. DEFRA (2015) also recommend that the following are considered before selecting a suitable laboratory:

- Training and Expertise of staff
- Measurement standards and guidance followed
- Third party accredited
- Participate and perform well in proficiency standards
- Order turnaround time, pricing, communication

After considering the above factors, the most suitable laboratory to supply and analyse the diffusion tubes was Environmental Services Group. The results from the AIR proficiency tests indicated that 100% of results submitted between April 2013 and November 2014 were satisfactory. The laboratory is also UKAS accredited and the method meets the requirements of the DEFRA Guidance: 'Diffusion Tubes for Ambient NO2 Monitoring: Practical Guidance.'

The results from the diffusion tubes were input to the SPSS database. This allowed for nitrogen dioxide levels to be connected with questionnaire responses. The following are examples of associations tested;

- Concern about air pollution and nitrogen dioxide level
- Knowledge of the health effects and nitrogen dioxide level
- Rating of air pollution and measured level of nitrogen dioxide
- Number of illnesses and nitrogen dioxide level
- Individual health conditions and nitrogen dioxide level

The inferential tests conducted in SPSS were similar to those in Study 1. For all tests conducted, statistical significance was considered at least 95% confidence level ($p < 0.005$). Within the results the p value is given for each test as an indication of the level of significance.

4.8 Study 3

Study 3 was designed to meet Objective 4 which states, 'Review Local Air Quality Management and highlight the importance to policy makers.' To achieve this objective, the following should be completed

- Identify Local Authorities with AQMAs for traffic
- Obtain the most recent Air Quality Action Plans

- Collect detailed information on the implementation of LAQM and its effectiveness
- Identity what information is currently available to the public on air pollution

4.8.1 Method

This study required the collection of in-depth information on the successes and failures of the implementing the current air quality management system. Due to the level of detail required, interviews were considered the most appropriate data collection method. An interview schedule was created and piloted amongst other academics. The piloting led to several changes being made to the structure of the interview. The final interview schedule was structured into three main sections: current air quality management areas, training provision and public information. The interviews were semi structured; the interview schedule provided structure, however reactive questions were also asked in response to the participant's previous replies. The interviews were recorded with permission from the participant. The recording meant all details of the interview could be transcribed. A copy of the interview schedule can be seen in **Appendix 3**.

To gain an insight into the public's awareness of Local Air Quality Management, interviews were conducted with participants from Study 2. The questions focused on their awareness of who to contact and where to get information on air pollution. The interview schedule can be seen in **Appendix 3**.

4.8.1.2 Pilot Study

The interview schedule was designed taking into consideration previous research to reduce the need for changes during the piloting process. The interview schedule was initially piloted among a small group of academics. This allowed for wording issues to be addressed and for the addition of new themes. In Northern Ireland there are 11 Local Councils therefore excluding some of these exclusively for a pilot study would reduce the total number of interviews. However, it was felt that a pilot was also necessary to ensure the interview schedule was effective. Therefore, it was decided to conduct an informal pilot process which involved conversations with several local councils. This ensured that the key themes were included within the

schedule. A small number of additions such as questions on the new air pollution strategy recently introduced in Scotland.

4.8.1.3 Participant Recruitment

In Northern Ireland there are 11 local councils and a total of 20 Air Quality Management Areas declared for Nitrogen Dioxide due to traffic. The air quality management areas are based across 8 local councils. All councils with Air Quality Management Areas for traffic related air pollution were asked to participate. They were contacted by both phone and email to encourage participation.

Participants from Study 2 who agreed for monitoring to be completed at their properties were also asked if they would be willing to complete a short interview. The interview collected data on their knowledge of available services in relation to air pollution. The second part of the interview explored the format in which they would like to receive information on air pollution if any.

4.8.1.4 Data Analysis

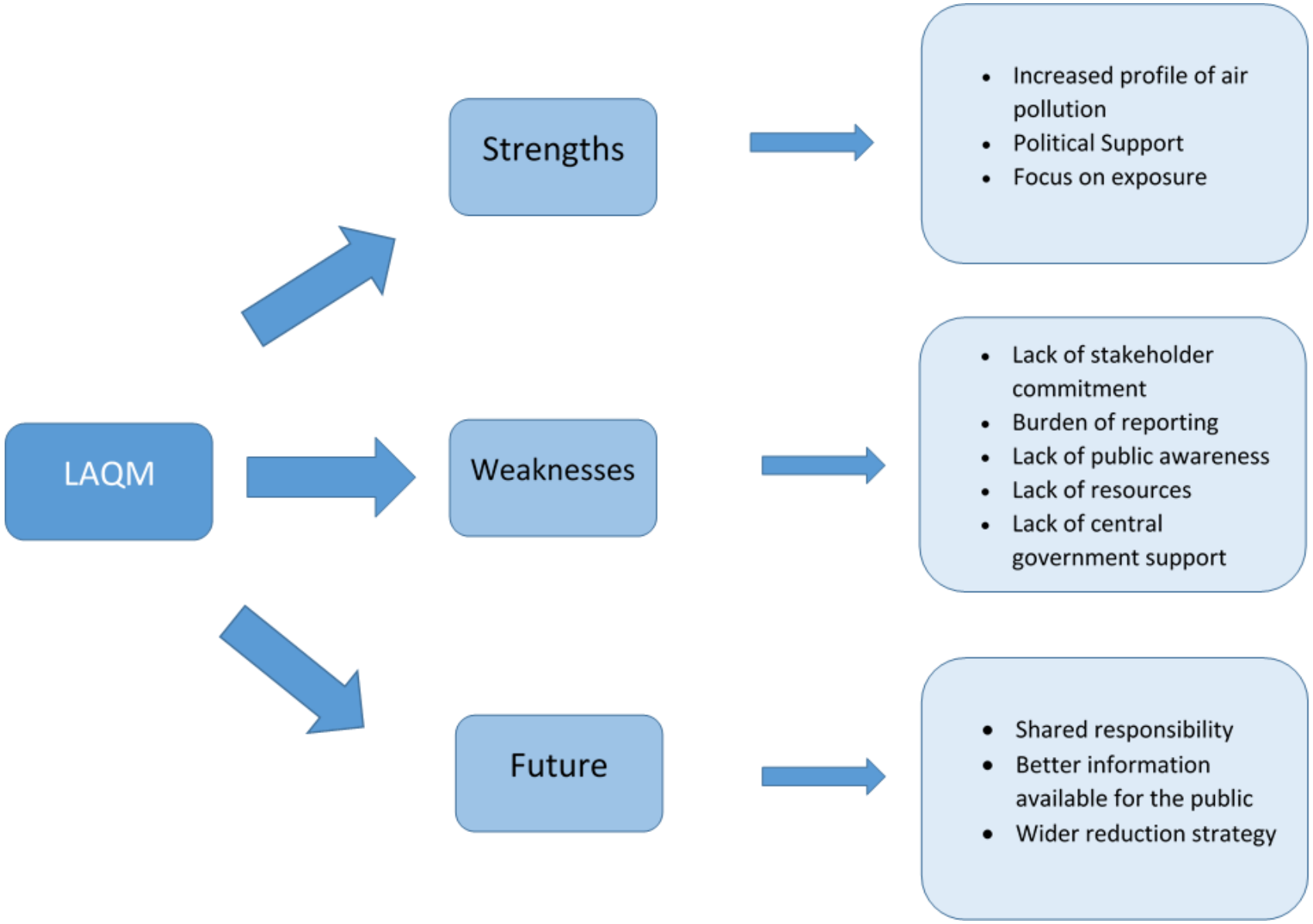
Study 3 comprised of the collection of qualitative data from both local authorities and residents. Nvivo software was chosen to manage, organise and analyse the data. Nvivo allows for the data to be organised into themes and for visual findings to be produced.

The interviews were recorded to ensure there was an accurate record of the participants' responses. Permission was gained from all the respondents to record the interviews. All interviews were transcribed by the researcher. This increased consistency and accuracy. Once transcribed, the transcription document was checked by listening to the interview again. This allowed for any errors to be identified and corrected. The researcher transcribing the interviews also allowed for greater familiarisation with the data which was beneficial when creating the coding framework.

Thematic analysis is defined as, 'a method of identifying, analysing and reporting patterns (themes) within data (Braun and Clarke, 2006). Thematic analysis was used to design a framework for analysis. The framework for analysing the interviews can be seen in **Figure 17**. The themes for the analysis included strengths and weaknesses

of the current Local Air Quality Management Regime and suggested future improvements.

Figure 17: Analysis Framework



4.9 Ethical Considerations

As the research involved contacting human participants it was vital to ensure that when designing the methodology the impact on the participants was considered and the safety of the researcher. There are four main aspects to consider when evaluating the ethical impact of the research including; avoiding harm to the participants, respecting the privacy of participants, avoiding deception and ensuring informed consent from the participants (Gray, 2014). Before data collection could begin, an Ethics Application was submitted to the Ulster University Faculty of Art, Design and Built Environment Research Governance Filter Committee. The following ethical implications were considered before completing the research:

- Concern

  The research may cause the residents to become concerned regarding the level of air pollution in their area and the potential impact which it could be having. To prevent this, the questionnaire was carefully worded and piloted before use. Furthermore, those who participate in Study 2, may become concerned or anxious after receiving the monitoring results. To reduce this concern, each set of results were accompanied with a tailor made information sheet. The information explained the levels found and included advice from DEFRA and NHS. The participants were also given a list of useful contacts for further information. An example information sheet can be seen in **Appendix 2**.

- Vulnerable Groups

  This research was not specifically targeting vulnerable groups such as the elderly or individuals with learning difficulties however they were not excluded from participating. Consideration was given to this when designing the questionnaire. It was designed to be clear and easy to understand. It was piloted before use to ensure it did not confuse participants and could be completed with ease. Furthermore, the length of the questionnaire was kept to a minimum. The questionnaire was completed in person therefore any concerns or difficulties which the participant had could be voiced at once. It

was explained to each participant that they were able to withdraw from the research at any point.

- Data Protection

  Participants may have been concerned that their identity could be established from the research. To overcome this, the respondents of both the questionnaires and the interviews were reassured that all information was anonymous. The data was stored securely in compliance with the Data Protection Act.

- Researcher Safety

  The research involved completing surveys door to door. In addition, Study 2 involved arranging a suitable time to meet the participants at their home for the monitoring equipment to the set up and then collected. This posed a risk of verbal abuse or physical threat to the researcher. There were several factors which could increase this risk including: collecting data during the hours of darkness, visiting participants' homes alone when setting up or collecting monitoring equipment and collecting data in deprived areas where there may be an increased danger. To minimise the risks, several precautions were implemented. Data was primarily conducted during daylight hours, when this was unavoidable the researcher was accompanied. At all times during the data collection, the researcher informed another adult of their location, expected time to be spent at the location and of their return. If the researcher at any point felt vulnerable or threatened, they left the location immediately.

Participant Information sheets were designed to outline what participating in the research would involve and to assure the participants that they could withdraw from the research at any time. In addition, a consent form was designed to allow the participants to indicate that they agreed to being involved and that they had read the information sheet. By completing these two steps the participants were indicating

their informed consent. The information sheet and consent form can be seen in **Appendix 2**.

Ethical approval was granted by the Research Governance Filter Committee indicating that all relevant concerns had been identified and suitable precautions had been taken to reduce the level of risk to both the researcher and the research participants.

4.10 Summary

The methods used in previous research were reviewed, specifically those focusing on traffic related air pollution and the management of air pollution. The review identified the most commonly used methods in the research field and allowed for the positives and negatives of each method to be considered. A mixed method approach was considered the most appropriate. The approach includes the use of questionnaires, diffusion tubes to monitor indoor and outdoor nitrogen dioxide and interviews. The next chapter states the results from the data collection.

Chapter 5: Results Analysis

5.1 Introduction

The research consisted of three studies collecting both quantitative and qualitative data. The previous chapter explained the methods used to collect and analyse the results obtained. The quantitative data was analysed using Statistical Package for Social Sciences (SPSS) and the qualitative data using NVivo. Details of the statistical tests used for analysis and can be found in the methodology chapter. The results from the three studies are presented in this chapter.

The chapter aims to meet the following objectives:

- Examine and illustrate the findings from Study 1, 2 & 3
- Determine the key findings from each study

5.2 Study 1 – Awareness and Knowledge of Air Pollution

Study 1 involved the use of questionnaires to collect quantitative data on the health of residents living in Air Quality Management Areas in Northern Ireland. Furthermore, information on the residents' knowledge and awareness of traffic as a source of air pollution in their area was collected.

5.2.1 Response Rate

The questionnaires were completed in 7 locations. An overall response rate was calculated and this was then broken down into a response rate for each location (**Table 12**). The overall response rate was 20%. 150 males and 189 females participated in the research. Dales Corner in Londonderry was identified as a location which met the selection criteria. The location was visited during the data collection period however no responses were received. The majority of the properties have been redeveloped for business use or at the time of data collection were vacant.

Table 12: Response Rate

Location	**Completed Questionnaires**	**Non-response**	**Response Rate**
Armagh	15	31	33%
Dungiven	10	18	36%
Glengormley	5	10	33%
Newry	162	913	15%
M1 Westlink Corridor	107	306	26%
Ormeau Road	13	37	26%
Upper Newtownards Rd	27	51	32%
Total	**339**	**1366**	**20%**

5.2.2. Results

5.2.2.1 Concern in relation to traffic related air pollution

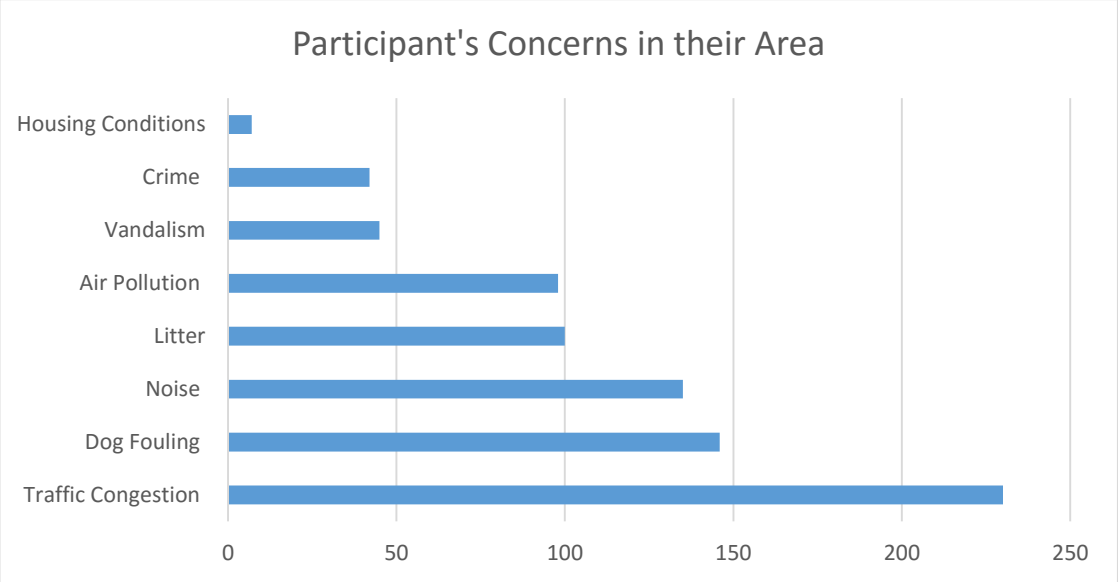
Participants were asked to rate their top three concerns about the area they live in. The mean value of each concern was placed in ascending order and compared. The **Table 13** summarises the results. The mean is used in the analysis to determine how highly the participants rated each concern. Traffic congestion has the highest mean. This indicates that when traffic congestion was chosen as a concern it was rated as a high concern. Air pollution had the lowest mean indicating that when chosen it was rated as a low concern.

Table 13: Participants Concerns about their Area

Concerns	N	Percentage	Mean	Standard Deviation
Traffic Congestion	230	68%	2.6217	0.59
Litter	100	29%	2.2700	0.83
Housing Conditions	7	2%	2.1429	0.90
Vandalism	45	13%	1.8889	0.80
Noise	135	40%	1.8593	0.68
Dog Fouling	146	43%	1.8493	0.80
Crime	42	12%	1.7857	0.75
Air Pollution	98	28%	1.6633	0.70

Table 13 also presents the percentage of respondents who chose each of the concerns. The concern which has the highest percentage and therefore chosen by the most participants was traffic congestion. Housing conditions has the lowest percentage therefore was chosen by a small number of participants. However, when selected it was rated highly hence it has a high mean of 2.1429. **Figure 18** illustrates the number of participants of people who chose each concern. 28% of participants rated air pollution as one of their concerns. The analysis illustrates it has the lowest mean. This indicates that although it was selected by more than a quarter of participants, it was rated as the lowest concern.

Figure 18: Number of participants who selected each concern



An overall score for each concern was calculated which can be seen in **Table 14**. The rating of 3 indicates it was the participant's highest concern and a rating of 1 indicates it is their lowest concern. The overall concern was calculated by multiplying each rating by the number of participants who selected it. A total was then calculated for each concern. Calculating the overall score gives an indication of the concerns most frequently identified by the participants and also considers the rating of their concern.

Table 14: Overall Concern Rating

Concern	**Rating**			**Overall Score**
	3	**2**	**1**	
Traffic Congestion	156	61	13	**603**
Dog Fouling	37	50	159	**270**
Noise	23	70	42	**251**
Litter	51	25	24	**227**
Air Pollution	11	43	44	**163**
Vandalism	12	16	17	**85**
Crime	8	17	17	**75**
Housing Conditions	3	2	2	**15**

Traffic congestion had the highest mean and the highest overall score. This indicates that it was rated as a high concern for a large number of participants. The issues of concern which had the lowest scores are housing conditions, crime and air pollution. Air pollution had the lowest mean indicating that when it was chosen it was a low concern. It also has the third lowest overall score in **Table 14** indicating that there is a low level of concern regarding air pollution.

The issues of concern identified were compared with the gender of the participants to determine if males and female were concerned about different issues. The analysis indicated that there was no significant difference between the concerns selected and the gender of the respondent. The issues of concern were also compared with location. The analysis indicated that there was no significant

difference between the location and the likelihood of selecting air pollution as a concern.

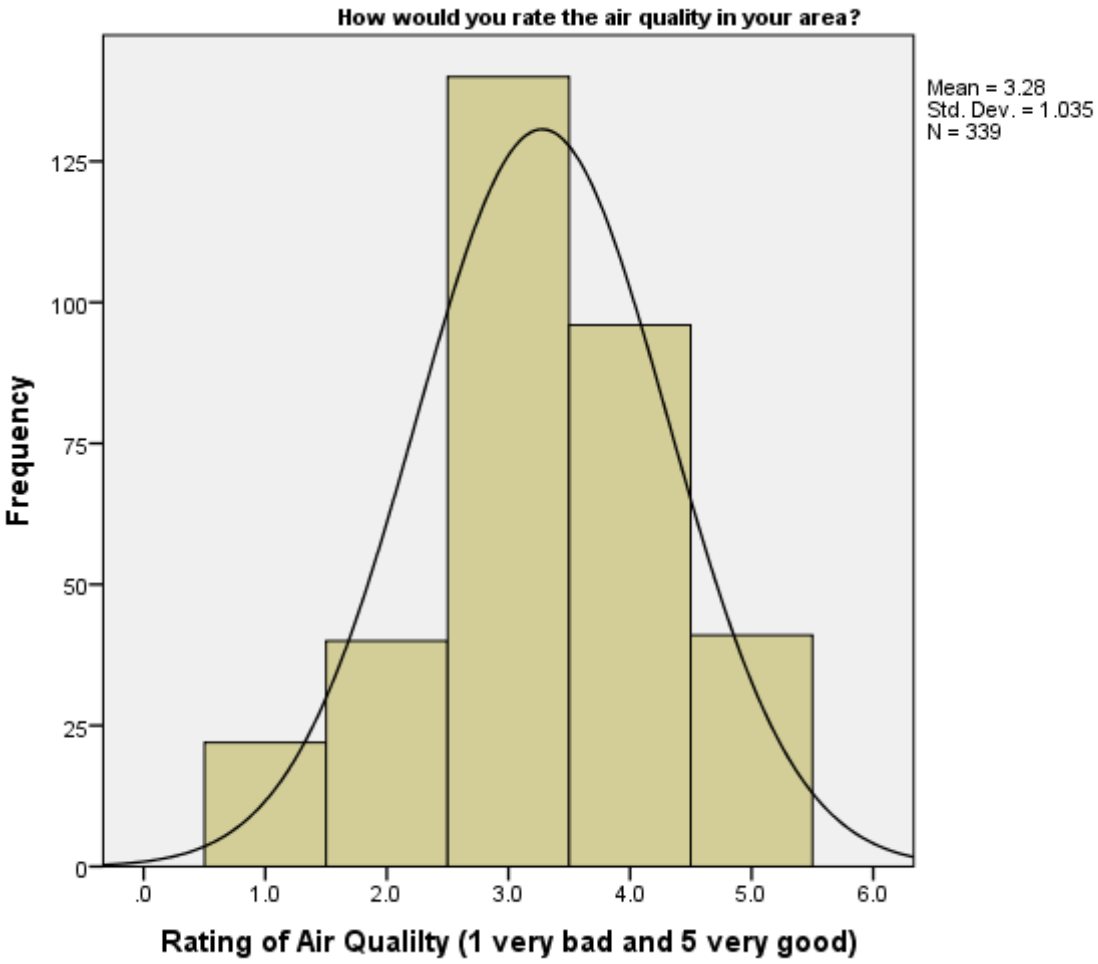
In addition to identifying the most concerning issues in their area, participants were asked to rate their level of concern about air pollution on a 5- point likert scale. Overall, 49% of respondents were not concerned or only slightly concerned about air pollution in their area. 29% were very concerned or moderately concerned about the air pollution in their area. The remaining 22% were unsure whether they were concerned or not.

A correlation (p=0.041) was found between the seven monitoring locations and the participants concern regarding air pollution. Participants living in Dungiven had the highest concerns about air pollution in their area. Significance was not found (p=0.5) between the participants age and their level of concern. This indicates that the age of the participant does not influence their level of concern. There was no significant difference between gender and rating of concern (p=0.894).

5.2.2.2. Rating of Air Pollution

The participants were asked to rate the air quality in their area on a five point likert scale. 7% of respondents rated the air quality in their area to be 'very bad'. 41% of respondents stated that the air quality was, 'neither good nor bad' and 12% stated that it was 'very good'. The results are illustrated in **Figure 19**. There was no significant difference between gender and the rating of air quality indicating that both genders were similar in their responses.

Figure 19: Rating of air quality in their area



The mean rating of air quality for each location was compared ($p<0.001$). Dungiven had the lowest mean, indicating the participants in Dungiven were more likely to rate the air quality in their area as bad or very bad. Newry had the highest mean, indicating the residents were more likely to have positive views on the air quality in their area. The mean score for each location can be seen in **Table 15.**

Table 15: Mean Rating of Air Quality in each Location

Location	Mean	N	Std. Deviation
Newry	3.475	162	.9536
Glengormley	3.400	5	.8944
Ormeau Road	3.385	13	1.1209
Newtownards Road	3.259	27	1.0952
M1 Westlink Corridor	3.140	107	1.0320
Armagh	2.800	15	1.1464
Dungiven	2.100	10	.9944
Total	3.277	339	1.0348

The residents rating of air quality was compared with the measured level of Nitrogen Dioxide from study 2. As the level of Nitrogen Dioxide increased, the participants were more likely to rate the air quality as 'good' or 'very good'. The result was significant for both indoor ($p<0.001$, $r= 0.168$) and outdoor ($p=0.005$, $r=0.143$) levels of Nitrogen Dioxide.

A strong negative correlation ($r=-0.638$, $N=339$, $P<0.001$) was found between the respondents rating of air quality and their level of concern. This indicates that respondents who rated the air quality in their area as very bad were also the most concerned about air pollution.

Further analysis found a correlation ($p<0.001$, $r=0.287$) between the respondents rating of air quality and their opinion of whether air pollution affected health. Those who considered the air quality in their area to be 'bad' or 'very bad' also thought that air pollution affected health.

5.2.2.3. Traffic Levels

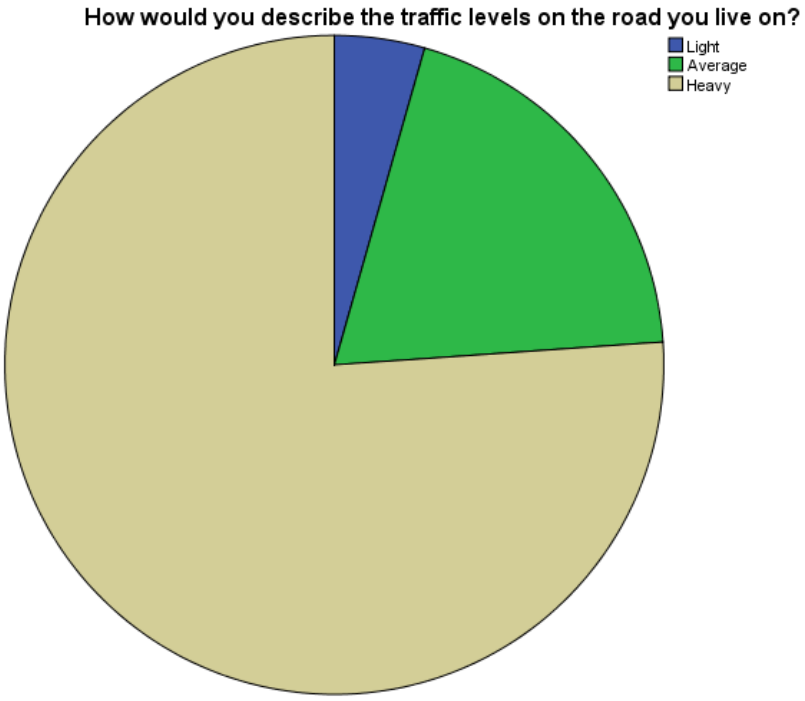
The locations chosen for the research are considered to have a high volume of traffic with a daily average of over 10,000 cars. Overall, 76% of participants stated the traffic levels were heavy in their area. The pie chart in **Figure 20** illustrates the respondents rating of traffic in their area. Analysis indicated that gender did not affect the rating of traffic levels, indicating that male and female respondents described the traffic levels in a similar manner. Significance was found between the

rating of traffic levels and the area which the respondent lived in (p=0.013, *df*=6). Residents in Dungiven, Glengormley and Upper Newtownards Road had a mean of 3 indicating that residents stated the traffic levels to be heavy. The results can be seen in **Table 16.**

Table 16: Location and Rating of Traffic Levels

Location	Mean	N	Std. Deviation
Glengormley	3.000	5	.0000
Newtownards Road	3.000	27	.0000
M1 Westlink Corridor	2.710	107	.5496
Dungiven	3.000	10	.0000
Ormeau Road	2.846	13	.3755
Newry	2.636	162	.5977
Armagh	2.733	15	.4577
Total	2.717	339	.5407

Figure 20: Description of traffic levels



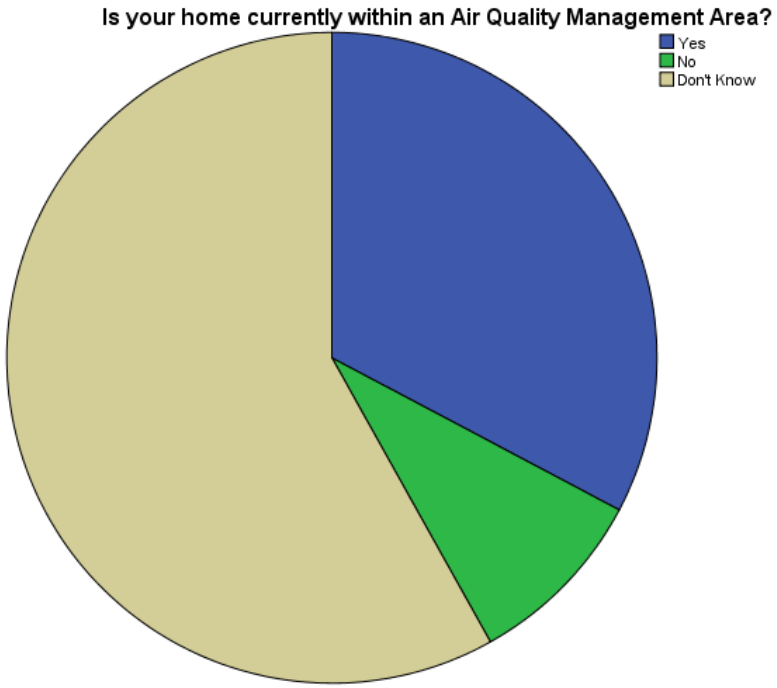
The respondents rating of the traffic levels was analysed with the daily average traffic count in each of the areas which is published by the Department of Infrastructure. The result was not statistically significant (p=0.182) indicating that the respondents rating of traffic levels did not reflect the measured traffic levels.

The participants who stated they were moderately or very concerned about air pollution in their area were more likely to rate the traffic levels as heavy in their area (p=0.006, r=0.150). Further analysis indicated that those respondents who rated the traffic levels to be heavy were also more likely to rate the air quality in the area as bad or very bad (p<0.001, r=0.228). A strong positive correlation (p<0.001, r=0.175) between stating the traffic levels as heavy and agreeing that exposure to air pollution can affect health.

5.2.2.4. Knowledge of Air Quality Management

All questionnaires were completed in Air Quality Management Areas. Analysis found that 33% of the respondents knew their home was within an Air Quality Management Area and the remaining respondents either wrongly identified that there home was not in an Air Quality Management or were unsure. The full results can be seen in **Figure 21**. The gender of the respondent did not significantly (p=0.09) influence the results however more women (51 of 189) than men (19 of 150) identified their home was within an AQMA.

Figure 21: Knowledge of AQMA



An Air Quality Management Area is defined as, 'an area which has exceeded or is likely to exceed the air quality objectives.' Of those questioned 91% did not correctly identify what an Air Quality Management Area was. Furthermore, 38% of respondents believed that it was an area where air quality was monitored and 24% believed that it was an area where you were not allowed to burn coal. There was no significant difference between gender and knowledge of what an Air Quality Management Area is. Females were more likely than males to admit that they did not know what an Air Quality Management Area was ($p=0.092$). Only 6 of the 339 respondents (2%) knew their home was in an Air Quality Management Area and were also able to correctly identify what an Air Quality Management was. 103 of the respondents (30%) incorrectly identified what an Air Quality Management Area was and then thought their home was within an Air Quality Management Area for that reason.

A statistically significant correlation ($p<0.004$) was found between respondents who knew their home was within an Air Quality Management Area and their level of concern. Respondents who knew their home was within an AQMA were less

concerned about air pollution in their area. Knowledge of their home being within an Air Quality Management Area did not significantly (p=0.121) affect the participants rating of air quality in their area.

5.2.2.5 Knowledge of the health effects associated with air pollution

In addition to obtaining the participants knowledge in regard to AQMA's, their knowledge of the health effects associated with exposure to air pollution was also obtained. 93% of the respondents agreed that air pollution can affect health. Respondents who strongly agreed that air pollution affects health were more concerned about air pollution in their area ($p<0.001$, $r=0.457$). As knowledge regarding the impact of air pollution increases, the level of concern about air pollution in the area also increases. All seven locations had similar views on whether air pollution affected health.

The respondents were asked if they thought air pollution would contribute to the following health effects: asthma, lower life expectancy, brain tumours, heart disease, reduced lung function, lung cancer, diabetes, stroke and kidney damage. The condition which was most recognised as being affected by air pollution was asthma (89%). Reduced lung function was also identified by 84% of the participants. 21% of respondents wrongly identified kidney damage as being affected by air pollution. In addition, 51% wrongly identified brain tumours as being affected by air pollution. The results are summarised in **Table 17**.

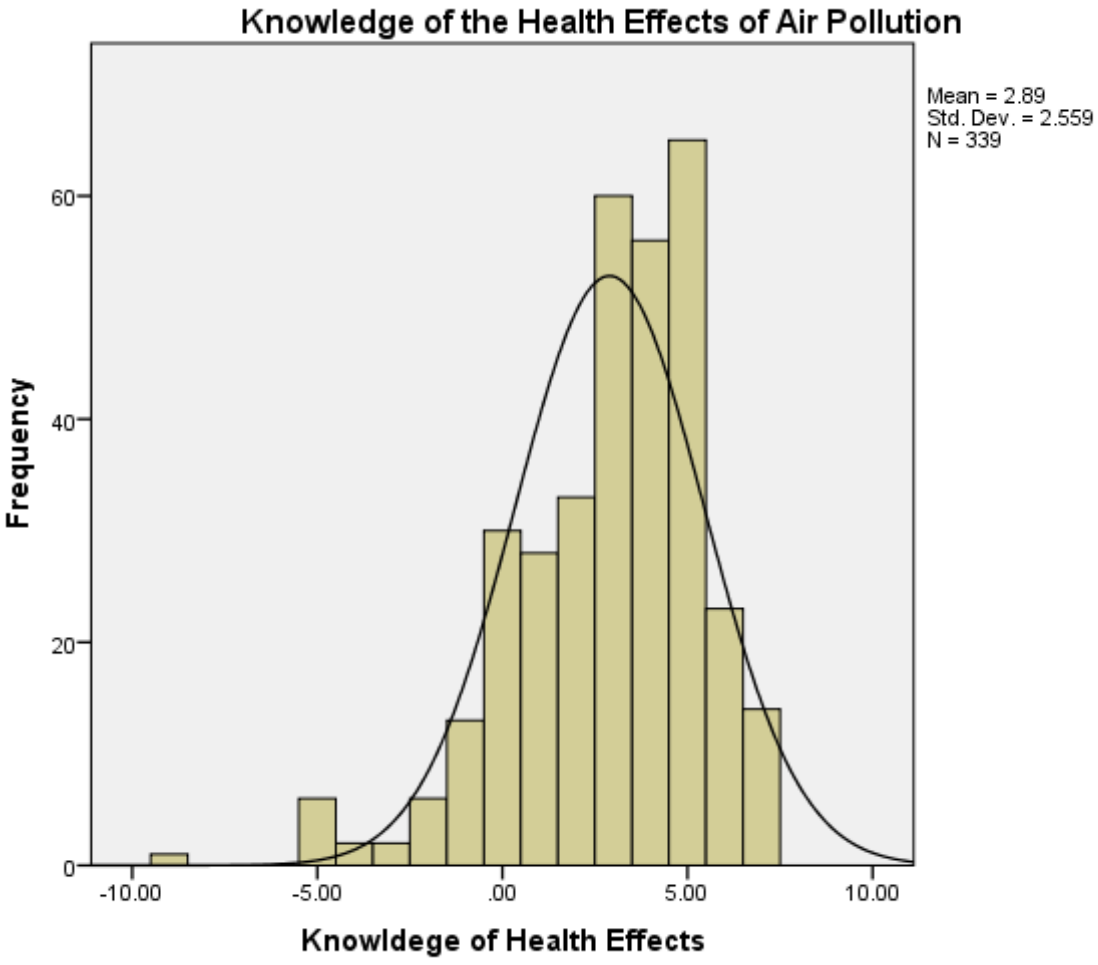
Table 17: Knowledge of health effects associated with exposure to air pollution

Health Condition	**Does air pollution contribute to these health conditions?**	
	N	**Yes**
Asthma	301	89%
Lower Life Expectancy	226	67%
Reduced Lung Function	284	84%
Lung Cancer	219	65%
Brain Tumour	173	51%
Stroke	95	28%
Heart Disease	79	45%

Diabetes	67	20%
Kidney Damage	67	20%

To give an overall understanding of the participants' knowledge, a simple rating system was devised. For each correct answer 1 point was given, each incorrect answer -1 and every unsure 0. If the respondent correctly identified all the potential health effects associated with exposure a total of 9 points was recorded. 1 respondent did not correctly identify any of the health effects leading to a score -of -9. The maximum score achieved by the respondents was 7/9. This was achieved by 14 of the 339 respondents. The mean score was 2.9 which indicates a low level of understanding of the health effects associated with exposure to pollutants from traffic. The knowledge of health effects is illustrated in **Figure 22**.

Figure 22: Knowledge of the Health Effects Associated with exposure to Air Pollution



Consideration was given to whether male or female respondents had a greater knowledge of the health effects associated with air pollution. There was no correlation found for the following health problems: diabetes, lung cancer, reduced lung function, heart disease, brain tumours and asthma. This indicates that both male and female respondents had similar knowledge of the health effects. For two health conditions there was a correlation with gender. More females (82 of 189) than males (59 of 150) knew that kidney damage was not affected by exposure to air pollution ($p=0.035$). However, males (56 of 189) were more likely than females (39 of 189) to identify that air pollution could impact upon the chance of having a stroke ($p=0.003$).

Respondents who rated the air quality as very bad or bad in their area were more likely to correctly identify a higher number of health conditions associated with air pollution ($r=-1.4$, $p=0.009$). Furthermore, those respondents who had a greater knowledge of the health effects associated with exposure to air pollution were more likely to be concerned about the pollution in their area ($r=0.229$, $p<0.001$).

5.2.2.5 Respondents Exposure to Air Pollution and the Health Impact

5.2.2.5.1 Exposure to air pollution

To obtain an understanding of the residents' exposure time to air pollution, respondents were asked to give the average number of hours they spend at the property. On average, the participants spent more time at home at the weekend with over half spending between 16-20hrs. During the week and at the weekends, participants spent at least 10 hours at their property. The results are summarised in the **Table 18, 19** and **Figure 23, 24**.

Table 17: Percentage of Time Spent at Home

Number of hours	Weekday	Weekend
10-15hrs	31%	5%
16-20hrs	42%	58%
21-24hrs	27%	37%

Table 18: Mean Number of Hours spent at the property

Number of hours spent at the property	**Mean (hrs)**	**SD (hrs)**
Weekdays	17	4.314
Weekends	20	2.554

The standard deviation in **Table 18** indicates that there was greater variation in the hours spent at home during the week. At the weekend, less variation was found. This indicates that on the whole people spent more time at home at the weekend compared to weekdays.

Figure 23: Number of hours spent at home during the week

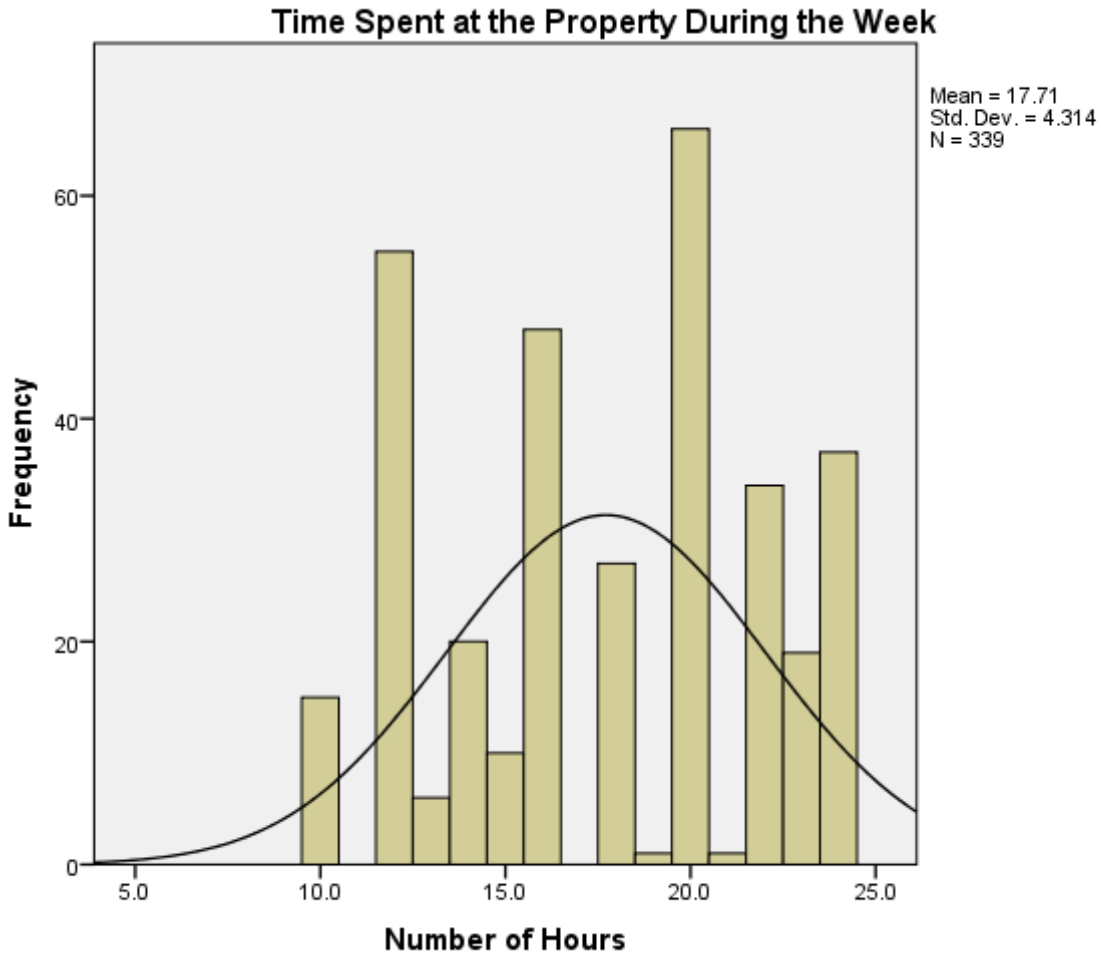
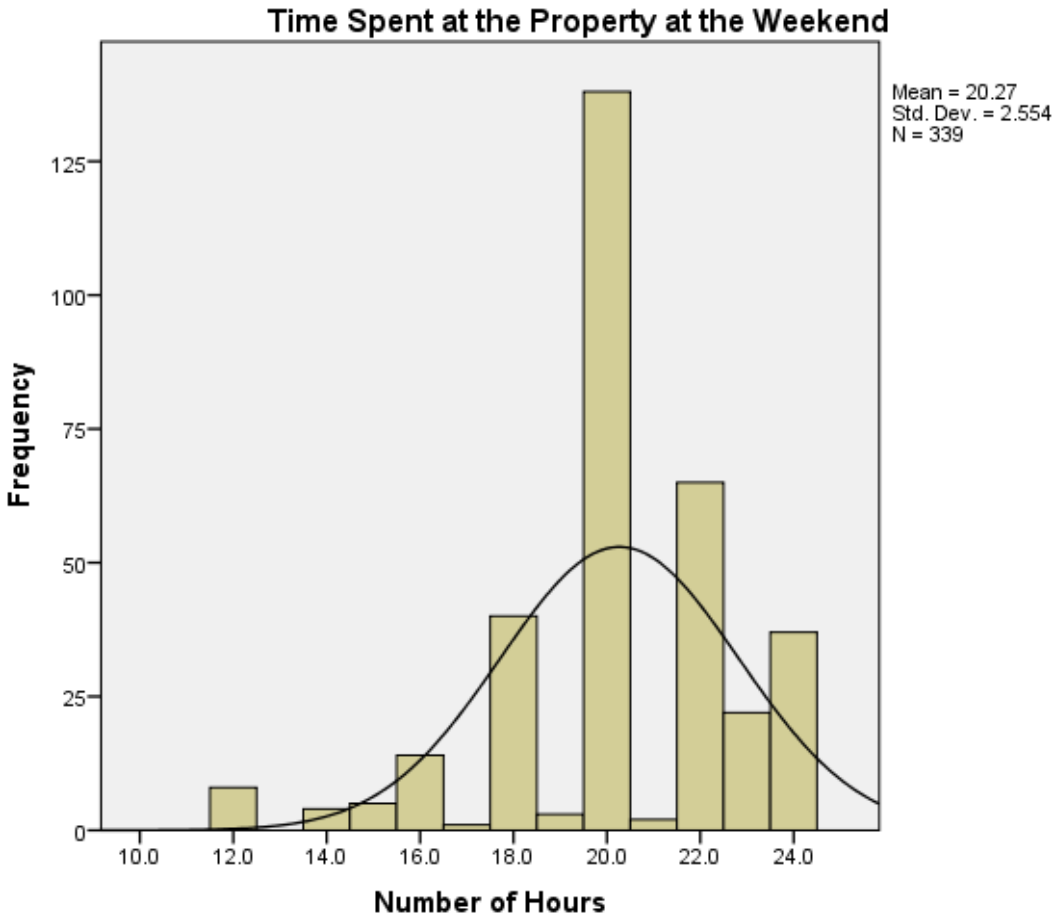


Figure 24: Number of hours spent at home at the weekend



5.2.2.5.2 Health Impact of Exposure to Air Pollution

Each respondent was asked if they had any of the health problems associated with air pollution. **Table 20** displays the number and percentage of people with each illness. 27% of respondents reported that they had asthma. Significance was found (p=0 .015) between the level of Nitrogen Dioxide measured in Study 2 and the number of people with Asthma. This indicates that as the level of Nitrogen Dioxide increases, the number of people with asthma also increases. Furthermore, an association was found between the number of people with asthma and the location (p=0.015, *df*= 6). Glengormley and the M1 Westlink Corridor has the highest percentage of respondents with asthma. **Table 20** states the percentage of people with asthma in each location.

Table 20: Percentage of respondents in each area with asthma

Location	**Level of Nitrogen Dioxide (µg m^{-3})**	**Number of respondents**	**Number of people with asthma**	**Percentage of people in each location with asthma**
Glengormley	41	5	2	40%
M1 Westlink Corridor	39.5	107	41	38%
Ormeau Road	37	13	4	31%
Armagh	20	15	4	27%
Newry	67	162	35	22%
Upper Newtownards Road	20.6	27	4	14%
Dungiven	50	10	0	0%

10% of respondents had hypertension. The number of respondents with hypertension was correlated (x^2 = 13.056, *df*= 6, P=0 .042) with the level of Nitrogen Dioxide. As the level of Nitrogen Dioxide increased, the number of respondents with hypertension increased. The location was also significant (p=0.042, *df*= 6) with the number of people with hypertension. Newry had 20 residents with hypertension. The percentage of residents with hypertension is illustrated in **Table 21**.

Table 21: Percentage of respondents in each location with hypertension

Location	**Level of Nitrogen Dioxide (µg m^{-3})**	**Number of people with hypertension**	**Percentage of people in each location with hypertension**
Ormeau Road	37	1	30%
Upper Newtownards Road	20.6	5	19%
Newry	67	20	12%
Dungiven	50	3	7%
Armagh	20	1	6%
M1 Westlink Corridor	39.5	4	3%
Glengormley	41	0	0%

The remaining health conditions including; lung disease, COPD, lung cancer, reduction in lung function, wheezing, shortness of breath, cardiovascular disease, stroke, diabetes, chest pains, angina and cancer were found not to be statistically significant with the level of measured Nitrogen Dioxide.

Table 22: Number of Respondents with Health Conditions

Health Condition	**Number**	**Percentage**
Asthma	90	27%
Hypertension	34	10%
Reduced Lung Function	8	2%
Lung Disease	7	2%
Wheeze	43	13%
Shortness of Breath	63	19%
COPD	14	4%
Hypertension	34	10%
Cardiovascular disease	21	6%
Stroke	17	5%
Diabetes	34	10%
Chest Pains	23	7%
Cancer	9	3%

The number of illness which a person had and their knowledge of the health impact of air pollution was investigated. The greater the number of illnesses a person had, the greater their knowledge about the health impact of air pollution ($p<0.001$).

The respondents were also asked to consider whether the air outside affected the air they breathe inside their home. 76% of respondents agreed the air outside could affect the air they breathe. In areas with a higher traffic volume, the respondents knew that the outdoor air could affect the air they breathe inside ($p<0.001$, $r= 0.173$).

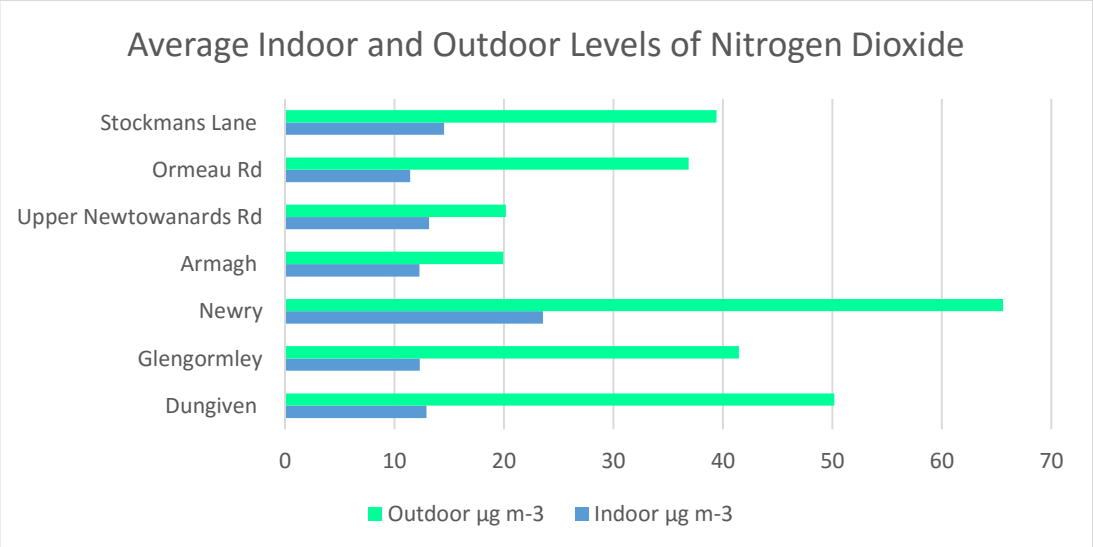
5.3 Study 2 – Exposure to Air Pollution

For Study 2, nitrogen dioxide levels were measured indoor and outdoor in 29 properties. In addition, 3 people also participated in personal monitoring. To consider the impact of seasonal weather changes, measurements were taken in January and June for four weeks. The distance of the property from the kerb was measured and the average temperature. **Table 23** states the mean level of Nitrogen Dioxide in each area, both indoor and outdoor for measurements taken in winter and summer. **Figure 25** visually illustrates the mean level of Nitrogen Dioxide in each location.

Table 23: Mean Level on Nitrogen Dioxide in each Location

Location	Winter		Summer	
	Indoor (µg m^{-3})	Outdoor (µg m^{-3})	Indoor (µg m^{-3})	Outdoor (µg m^{-3})
Armagh	12.60	25.30	11.95	14.65
Dungiven	13.72	59.68	15.58	57.14
Glengormley	7.77	40.50	21.55	42.40
Newry	23.53	68.20	23.60	62.93
Ormeau Road, Belfast	10.30	39.90	12.56	33.63
Stockmans Lane, Belfast	11.62	42.12	17.34	36.63
Upper Newtownards Road, Belfast	8.98	26.23	11.50	15.20

Figure 25: The Average Level of Indoor and Outdoor Nitrogen Dioxide



There was a strong positive correlation between the level of Nitrogen Dioxide from the diffusion tubes and the level from the automatic monitoring station in winter ($p=0.002$) and summer ($p<0.001$). This correlation indicates that the results obtained from the diffusion tubes are similar to those from the automatic monitoring station therefore increasing the reliability of the results. **Table 24** displays the average level of nitrogen dioxide from the monitoring stations and the average level from the diffusion tubes. The average difference between the results is 5 $\mu g\ m^{-3}$.

Table 24: Average Level of Nitrogen Dioxide from Automatic Monitoring Station and Diffusion Tubes

Location	**Automatic Monitoring Station**	**Diffusion Tubes**	**Difference between Nitrogen Dioxide Levels ($\mu g\ m^{-3}$)**
	Average Nitrogen Dioxide Level ($\mu g\ m^{-3}$)	Average Nitrogen Dioxide Level($\mu g\ m^{-3}$)	
Armagh	19	20	1
Dungiven	43*	58	15
Glengormley	40	41	1
Newry	67**	66	1
Ormeau Road	30	37	7
M1 Westlink Corridor	45	39	6
Upper Newtownards Rd	32	27	5

* The automatic monitoring in Dungiven was not working in June 2015 therefore the result in the table is only the winter level.

**The Canal Street monitoring station was not working in the months the monitoring took place. The nitrogen dioxide level is taken from the Bridge Street monitoring station.

Table 25 displays the mean outdoor nitrogen dioxide levels and states whether the level meets the current annual objective for nitrogen dioxide. The current annual mean objective for nitrogen dioxide is 40$\mu g\ m^{-3}$. Three locations were above the limit

including Newry, Dungiven and Glengormley. M1 Westlink Corridor was borderline with a monitoring result of 39 µg m-3.

Table 25: Mean Outdoor Nitrogen Dioxide Level

Location	**Nitrogen Dioxide Level (µg m^{-3})**	**Does this meet the legal requirement?**
Newry	66	No
Dungiven	58	No
Glengormley	41	No
M1 Westlink Corridor	39	Yes
Ormeau Road	37	Yes
Upper Newtownards Road	27	Yes
Armagh	20	Yes

Monitoring was completed in both winter and summer. A correlation ($p<0.001$) indicated that the difference between summer and winter levels of nitrogen dioxide is similar between each location. As the winter level of Nitrogen Dioxide increases so does the summer level. **Table 26** shows the mean level of Nitrogen Dioxide in each location. The outdoor level of Nitrogen Dioxide was higher in the winter in all locations except Glengormley. The indoor level of Nitrogen Dioxide was higher in the summer in all locations except Armagh. The average temperature during the winter monitoring was 6˚C and in the summer the average temperature was 16˚C. Correlation was found between the level of Nitrogen Dioxide and the temperature level in both winter and summer. In winter there was a strong positive correlation ($p=0.007$) between the temperature level and the level of Nitrogen Dioxide. This indicates that as the temperature level increases so does the level of Nitrogen Dioxide. However, this might only apply up to a certain temperature level as negative correlation was found between the summer temperature level and the level of Nitrogen Dioxide. As the summer temperature level increased the level of Nitrogen Dioxide decreased ($p=0.003$). These results indicate that season and temperature may impact on levels on Nitrogen Dioxide.

A strong, negative correlation was found between the level of outdoor Nitrogen Dioxide and the distance of the property from the road. In winter ($r=-0.695$, $p<0.001$) and in summer ($r=-0.771$, $p<0.001$), the properties a greater distance from the road had lower measured levels of Nitrogen Dioxide. The average distance from the road in each location and the average Nitrogen Dioxide level is displayed in Table 24. It was decided to take two outdoor measurements at a property in Newry which had high levels of outdoor Nitrogen Dioxide during the winter (97.3 µg m^{-3}). During the summer, diffusion tubes were placed on the front and rear façade of the property for 4 weeks. At the front of the property the measurement was 95.5 µg m^{-3} compared to 28.74 µg m^{-3} at the rear of the property. This result also illustrates the impact which distance can make to the level of Nitrogen Dioxide.

Table 26: The average distance from the road and the average level of nitrogen dioxide

Location	**Distance from the kerb**	**Average Nitrogen Dioxide Level (µg m^{-3})**
Armagh	27m	20
Upper Newtownards Rd	21m	27
M1 Westlink Corridor	18m	39
Glengormley	9m	41
Ormeau Road	9m	37
Newry	4m*	66
Dungiven	2m	58

*Two of the houses in Newry were 1.6m from the kerb and one house was 26m from the kerb.

A strong, positive correlation was found between indoor and outdoor levels of Nitrogen Dioxide. The correlation was found in the monitoring results for both winter ($r=0.394$, $p<0.001$) and summer ($r=0.556$, $p<0.001$). This indicates that as the level of Nitrogen Dioxide increases outside, the indoor level also increases. The average indoor and outdoor levels for each location is displayed in **Table 27**.

Table 27: Average Indoor and Outdoor Levels of Nitrogen Dioxide

Location	**Average Indoor Nitrogen Dioxide Levels (µg m^{-3})**	**Average Outdoor Nitrogen Dioxide Level (µg m^{-3})**
Armagh	12	20
Dungiven	13	58
Glengormley	12	41
Newry	24	66
Ormeau Road	11	37
M1 Westlink Corridor	15	39
Upper Newtownards Rd	12	27

The indoor- outdoor ratio (I/O ratio) was calculated using the following equation;

$$\mathrm{I/O\,ratio} = \frac{C_{\mathrm{in}}}{C_{\mathrm{out}}},$$

Where C_{in} is the indoor concentration and C_{out} is the outdoor concentration.

The I/O ratio was calculated for all properties in both winter and summer. All properties had an I/O ratio less than 1. The lowest indoor-outdoor ratio was 0.10 which was found in Glengormley. The highest indoor outdoor was 0.95 which was found in Armagh. All ratios were higher in summer than in winter. **Table 28** summarises the average I/O ratio each location in both winter and summer. The full I/O ratio results can be seen in **Appendix 5**. I/O ratios below 1 are considered to be low and indicate that there are few indoor sources of air pollution. Higher I/O ratios are usually found in properties with residents who smoke and if measurements are taken in kitchen with a gas stove (Chen and Zhao, 2011).

Table 28- Average Indoor/ Outdoor Ratio for Summer and Winter

Location	**Winter I/O Ratio**	**Summer I/O Ratio**
Armagh	0.49	0.81
Newry	0.38	0.48
Upper Newtownards Rd	0.34	0.75
Ormeau Road	0.27	0.38

M1 Westlink Corridor	0.27	0.39
Glengormley	0.22	0.51
Dungiven	0.17	0.26

A positive correlation between the annual average number of vehicles per day and the outdoor level of Nitrogen Dioxide ($p<0.001$) was found. As the average number of vehicles increased, the average level of outdoor Nitrogen Dioxide also increased. No association was found between the level of indoor Nitrogen Dioxide and the annual average number of vehicles.

Table 29: Annual Daily Average Number of Vehicles and Average Nitrogen Dioxide Level

Location	**Annual Daily Average Number of Vehicles**	**Average Nitrogen Dioxide Level ($\mu g\ m^{-3}$)**
Armagh	10240	20
Dungiven	14590	58
Glengormley	11470	41
Newry	17250	66
Ormeau Road	25200	37
M1 Westlink Corridor	32840	39
Upper Newtownards Rd	15000	27

One of the properties where indoor and outdoor monitoring was completed had a large evergreen hedge. The impact of the hedge was explored by placing a diffusion tubes at each side of the hedge. The level recorded at the roadside of hedge was 48.6 $\mu g\ m^{-3}$ compared to 35.3 $\mu g\ m^{-3}$ at the side closest to the property. This indicates that the hedge may have provided a barrier to reduce the levels of Nitrogen Dioxide.

The level of measured Nitrogen Dioxide was compared with the respondents rating of air quality in their area. A negative correlation was found ($p=0.005$) which demonstrated that as the measured levels of Nitrogen Dioxide increased, the participants were more likely to rate the air quality as 'good' or 'very good'. This indicates a lack of awareness from the residents about the air quality in their area.

This is further shown through an association between concern and the level of Nitrogen Dioxide (p=0.027). As the level of Nitrogen Dioxide increased the respondents level of concern decreased. The Nitrogen Dioxide levels were also analysed with the respondents' description of the traffic levels.

Three of the participants from Study 2 also took part in personal monitoring. 2 of the participants where from Newry and 1 from Armagh. The personal monitors were worn for 1 week and diffusion tubes were also placed on the façade of the property and indoors for 1 week to allow for a comparison. **Table 30** states the average personal level of exposure to Nitrogen Dioxide along with the average indoor and outdoor level at the property for both winter and summer. The higher the indoor and outdoor levels, the higher the level of personal exposure. Participants were asked to keep an activity diary to allow for any differences to be accounted for. One of the residents in Newry was cooking for 4 hours which could account for the high level of personal exposure.

Table 30: Personal Exposure Levels of Nitrogen Dioxide

Location	**Average Personal Level (µg m^{-3})**	**Average Indoor Level (µg m^{-3})**	**Average Outdoor Level (µg m^{-3})**
Newry	23.4	26.1	84.1
Newry	10.73	27.12	64.15
Armagh	9.00	13.43	18.58

5.4 Study 3 – Local Air Quality Management

To identify the effectiveness of local air quality management in Northern Ireland, interviews were conducted with local councils. There are currently nine councils with Air Quality Management Areas declared due to traffic related air pollution. All nine councils agreed to be interviewed. A further 22 interviews were conducted with willing participants from Study 2 to gather their views on the availability of information.

5.4.1. Identifying and Reviewing Air Quality Management Areas

To begin the interviews, the respondents were asked practical details about the Air Quality Management Area in their borough. Respondents were asked about the

methodology used to identify areas with high levels of air pollution and the frequency of how often these areas are reviewed.

All of the councils included within the study have either passive monitors, automatic monitors or both within their district. The respondents were asked what method was used to determine where to site the monitors and how often the sites are reviewed. Six of the nine councils stated following DEFRA's Local Air Quality Management Technical Guidance as the main method of determining where to site monitors. The guidance states that monitors should be placed in 'relevant locations' where exposure is likely to be at its highest level. Other methods used include: local knowledge and areas where complaints or concerns have been raised by the residents. One of the councils employed an external consultant to review their existing automatic and passive monitoring sites and make recommendations on potential methods of improving their monitoring strategy.

Changes in an area such as new housing developments or industrial developments can impact on the local air quality levels. Taking this into consideration, reviewing monitoring sites should be a regular occurrence by local councils to ensure exceedances are identified and human health is protected. Three of the councils stated the monitoring sites were reviewed on an annual basis and two councils stated every 'couple of years'. The remaining 4 councils were more hesitant in their response with one admitting that a review of monitoring 'rarely' occurs. One respondent stated, *'there is no formal procedure, but it is something we are aware of that needs to happen.'* Although the councils are aware that they should review their monitoring strategy, it is demonstrated through the responses received that for almost half of the respondents it is rarely completed.

To declare an Air Quality Management Area, the location has to exceed or likely to exceed the limits set out in legislation. Each council was asked to clarify if their AQMA was declared on the basis on monitoring, modelling or a combination of the two methods. Seven of the councils stated that the area was declared based on modelling and monitoring results and 2 of the councils declared areas based on monitoring results alone.

There is inconsistency in the size of Air Quality Management Areas in Northern Ireland for example there is an AQMA which has one side of a street compared to an AQMA which encompasses a whole city. The rationale underpinning the decision-making process for boundary setting was considered in the interviews. The methods used by the Local Councils can be seen **Table 31**. The most commonly used approach was modelling to determine the boundaries for an AQMA. Modelling allows for the dispersion of the pollutant to be considered by entering details such as wind speed and built environment features. The road layout and traffic flow are also methods used.

Table 31: Method used to determine the boundaries of an Air Quality Management Area

Method	Number of Councils using the Method
Modelling	4
Considering the traffic flow and road layout	2
Main Commuter routes	1
Monitoring	1
Aligned with smoke control zones	1

Local Councils with AQMA's are required to produce an Action Plan which contains measures to reduce the levels of air pollution in the area. One respondent agreed that the measures identified had led to a reduction in the roadside levels of nitrogen dioxide. The remaining councils were more hesitant with their response. 2 respondents stated that it is difficult to link the measures with a reduction in nitrogen dioxide. A further two respondents stated that they did not believe the action plan had led to any reductions. One respondent stated that the actions contained within the plan are 'limited' and are sometimes 'aspirational' rather achievable. It was also stated that sometimes the measures contained within the plan are to provide 'civic leadership'. The council updating their fleet to electric vehicles provides an example for residents within the borough to follow. The progress of the action plans is required to be reviewed on an annual basis but the majority of councils agreed that

there is little progress within a year, especially in relation to traffic emissions therefore reports are often repetition from the previous year.

5.4.2. Strengths of Local Air Quality Management

The interviews gathered several positive comments on local air quality management. The process of identifying and reviewing the levels of air pollution has increased the profile of the problem in local councils. If there was no legal responsibility to complete the work, the levels of air pollution would have remained unknown. The interviewees also positively commented on the focus which local air quality management places on receptors. The areas are only declared where the public are likely to be exposed. Concern was raised by one of the respondents about the indoor levels not being considered therefore making it difficult to determine actual exposure levels. Furthermore, another respondent questioned the scientific evidence behind the 40µg m^{-3} limit.

The majority of respondents agreed that there is political support for local air quality management. The government included air quality as one of their indictors in the Programme for Government in 2016. Two of the respondents were more cautious with their responses indicating that although councillors may seem interested in air pollution, the lack of funding and priority it receives indicates a different approach. It has been suggested that the profile of air pollution needs to be raised in the political arena and the health impact highlighted for meaningful action to be taken.

5.4.3 Weaknesses of Local Air Quality Management

The reporting aspect of Local Air Quality Management was one of the weaknesses identified. The respondents agreed that reporting needs to be completed but the current format and time scale is unsuitable. Respondents stated that the reporting was, 'repetitive' and requires 'streamlining'. It was agreed that there is little activity in a year therefore reports are often a duplication of the previous year.

The availability of resources such as time and money was another concern among the respondents. In relation to money, all councils agreed that the availability of funding from DEARA had decreased in recent years. For some councils this has impacted their monitoring and for one has led to the loss of a technical officer

employed specifically for air pollution. Time given for air pollution work was another concern which can be seen through the following quotes:

'*I think there is probably an under estimation of the amount of time the work takes and with all the other things we need to deal with.*'

'In terms of time, I don't believe there is enough time'

'We had reductions in our grants from DOE and we did have a technical officer post who was funded from the Local Air Quality Management Grant. We lost that funding, so we don't have that post anymore. So there definitely is for us a difference and I suppose other staff are having to take on those responsibilities.'

The majority of the interviews indicated that staff would like to spend more time on air quality work but have to deal with reactive work which takes priority. One council stated that if the health implications of air pollution were understood by government, it would be higher on the agenda therefore gaining more momentum.

There are several negatives identified from the interviews which indicate that further action is required for local air quality to be successful in reducing public exposure to levels of air pollution which have the potential to impact health. One respondent strongly stated, '*I honestly don't believe it has any success. Honestly, I think our air quality issues, our air quality has not improved.'* The lack of progress in reducing air pollution can lead to low morale with one interviewee stating, *'I don't think there has been great improvements and it can be frustrating.'*

5.4.4. Stakeholder Commitment

The local councils identified the stakeholders who they consult with. **Table 32** displays the list of stakeholders.

Table 32: Stakeholders

Stakeholders	**Number of References**
Transport NI	8
Translink	7
Planning Department	5
Public	3
Department of Infrastructure	2
Freight Association	2

Sustrans	2
Travelwise	2
Councillors/ MLAs	1
DEFRA	1
Road Haulage Association	1

The commitment of stakeholders was an area of local air quality management which divided the respondents. Some of the councils stated that stakeholders readily sent information when asked to contribute and it was an opportunity for councils to make them aware of the current issues. Furthermore, it allowed for contacts to be established in other organisations. Although stakeholder engagement has provided some benefits there were several councils stating that more needs to be done. The communication between stakeholders was described as 'one way'. The information was provided but there was little other action completed. Several councils also stated that the people that they were in contact with were not at the 'right level'. Projects which would reduce air pollution often require large budgets therefore require management level decisions are required.

5.4.5 Suggestions for future improvements to Local Air Quality Management

There were many suggestions on how Local Air Quality Management could be adapted to create a more effective system. The suggestions are described below.

All councils agreed that they alone cannot reduce air pollution. It needs to be a shared responsibility among a variety of different agencies. Currently the system requires the council to consults with other stakeholders. Problems have been encountered with this as other agencies are not legally required to contribute. This is demonstrated in the quotes below;

'*We are facilitating this, we need to take the focus away from what the council can do and move it away to what these other agencies need to be doing. '*

'Because if it is not your responsibility to actually write the report then you are not going to do it. Yes, so I do think it does need to be shared. '

The majority of respondents agreed a wider reduction strategy is required. This would broaden the focus from small hot spots to whole cities or national reductions

in air pollution. Taking this approach would allow for greater benefits for the whole population. One respondent described air pollution as having, 'no boundaries' implying that the focus of reduction should not be limited to within air quality management areas.

A change in the information available was an aspect which the majority of councils believed there could be improvement. Behaviour change is required to encourage the use of sustainable transport methods. For change to occur the public need to be made aware of the impact of their current travel behaviours and the alternative choices which are available.

5.4.6 Availability of Information on Air Pollution

The 9 interviews with Local Authorities were complemented with 22 interviews with residents living in Air Quality Management Areas. The interviews with residents focused on their awareness of who to contact regarding air pollution, their knowledge of available air pollution information and the identification of how they would like to receive information in the future.

The local councils identified several sources of information which are available to the public. The sources included the Air Quality NI website, council websites, DEFRA website and the Air Aware text service. When the residents were asked about their awareness of information, 2 of the 22 interviewed stated that there was a website. 19 of the respondents were not aware of any information and a further 1 stated that the media provided information. All of the residents interviewed stated that they would like more information on air pollution. There were several different types suggested. **Table 33** displays the suggested communication methods from the residents. One resident stated that the information would only be useful if it was regularly updated and was communicated in a manner that is easily understandable.

Table 33: Preferred Media to Receive Air Quality Information

Method	**Number of References**
Website	11
Local Newspaper or TV ad	9
Letter	5

Social Media	4
Email	1

The majority of local councils felt the current information available to the public was adequate. They felt that all the information which the public would require can be accessed through the Air Quality NI website. Several commented that they are not inundated with requests therefore they believe that they public are not interested in further information. Two of the Councils acknowledged that there needs to more information and a different message needs to be communicated. The current information was described as 'technical' whereas a 'proactive' message is required. One council suggested that the use of social media such as Facebook or Twitter could be an approach which would raise public awareness of air pollution issues.

Under half of the residents knew to contact their local council if they were concerned about air pollution in their area. The remaining participants did not know who to contact, with 1 suggesting the Environment Agency. Others suggested they would search the internet. In addition, none of the residents interviewed were aware of any action being taken in their area to reduce the levels of air pollution.

5.5 Key Findings

The key findings from each study are outlined below;

Study 1

- Air pollution is not considered a high concern by residents living in AQMAs
- As knowledge of air pollution increases, concern about air pollution increases
- Higher levels of Nitrogen Dioxide led to a greater incidence of respondents with asthma and hypertension
- Low level of knowledge about air pollution levels, health effects and air quality management
- Residents in AQMAs are unaware of the levels of air pollution they are exposed to

Study 2

- Residents in AQMAs are being exposed to levels of Nitrogen Dioxide that exceed the current legal limit
- The greater the distance from the road, the lower the levels of Nitrogen Dioxide
- The level of Nitrogen Dioxide is affected by temperature levels
- The majority of time spent is indoors therefore it is a significant exposure location
- The level of indoor Nitrogen Dioxide is related to the level of outdoor Nitrogen Dioxide

Study 3

- LAQM is successful in identifying hot spot areas but has not produced the required reductions in air pollution levels
- Measures identified in Action Plans are not always realistic or achievable
- The Air Quality Management process has increased the profile or air pollution amongst professionals
- The current reporting requirements are ineffective in reducing levels of air pollution from traffic
- Future improvement requires commitment from stakeholders, a wider reduction strategy and an increase in public awareness
- Residents within Air Quality Management Areas have little awareness of where to get information on air pollution or the current work in place by local councils to reduce air pollution in their area. Communication with the public needs developed.

This chapter has outlined the results from Study 1, 2 and 3. The results have indicated that residents living in AQMAs are being exposed to levels of nitrogen dioxide higher than the legal limit. This exposure may be impacting upon the health and well-being of the residents. Higher levels were associated with an increase in incidence of asthma and hypertension. A low level of awareness about exposure to air pollution and the impact which it can have was found among the residents. The current LAQM

system has been useful in identifying areas of high pollution but has failed to reduce levels to the legal limit. **Chapter 6** discusses the results in greater depth along with results from similar published studies.

Chapter 6: Discussion

6.1 Introduction

The previous chapter examined the results from Studies 1, 2 and 3. This chapter discusses the findings in greater detail and positions them within current published literature. The participants concern, awareness and knowledge of traffic related air pollution is discussed along with the measured levels of nitrogen dioxide. The adequacy of Local Air Quality Management and the implications of the research on the future delivery is discussed. The chapter evaluates the validity of the results and reflects upon the limitations of the research approach.

6.1.1 Aims and Objectives

This chapter interprets and discusses the significant findings from Chapter 5 and states the contribution to knowledge of the research by discussing the results with current published literature.

The aim of this chapter is;

to discuss the key findings from Study 1, 2 & 3 in relation to current published literature and state how the research could influence future policy and practice in relation to traffic related air pollution.

The aim will be met by completing the following objectives:

- To consider the link between public awareness, concern and knowledge of traffic related air pollution
- To compare the measured levels of indoor and outdoor nitrogen dioxide levels in Northern Ireland with levels from other studies
- To consider the effectiveness of Local Air Quality Management in reducing exposure to traffic related air pollution and compare with the methods used in other countries
- To state the limitations of the research and the steps taken to minimise the impact of these
- To identify areas for future research and identify the impact of research for policy development and practice

6.1.2 Key Themes

This chapter discusses in more detail how the findings of the research met the overarching aim of research and the objectives. Furthermore, the chapter demonstrates the impact this research has in addressing the current research gaps which were identified in Chapter 3. The findings will be discussed along with the relevant literature in 4 key themes. The key findings from each them are highlighted below:

- **Awareness and knowledge of air pollution**
  - There is a low level of knowledge among residents in air quality management areas about the impact of exposure to traffic related air pollution
  - Residents of air quality management areas are unaware of their level of exposure to traffic related air pollution
  - As knowledge about the impact of air pollution increases, concern about air pollution also increases
- **Indoor and Outdoor Nitrogen Dioxide Levels**
  - The majority of time is spent indoors and therefore is a significant exposure location
  - As outdoor nitrogen dioxide levels increases, indoor levels also increased
  - As distance from the road increased, nitrogen dioxide level decreased
- **Evaluation of Local Air Quality Management**
  - Local air quality management has been successful in identifying areas were levels exceed the legal requirements however has failed to deliver the reductions required
  - Reporting and stakeholder engagement were identified as the main problem areas
- **Future Improvements**
  - Future improvement will rely on the development of greater stakeholder engagement, a wider reduction strategy and an increase in public awareness

- Communication with the public about air pollution needs greater development

Each of the key themes are discussed in greater detail and positioned in relation to current literature.

6.2 Awareness and Knowledge of Air Pollution

As the measured level of nitrogen dioxide increased, participants within the research were more likely to rate the air quality in their area as good. The results have indicated that those who are exposed to the highest levels of air pollution are less likely to be aware of their exposure. Previous research on awareness and knowledge of air pollution has primarily been conducted in in 1960s-1970s (Blacksell, 1972., Kirkby, 1972., McBoyle, 1972., Billingsley, 1974/1975., Wall, 1974). Due to changes in the main source of exposure and the increased amount of available information, up to date research was required. In addition, previous research focused on the perception of air pollution of those living in close proximity to polluting industries (Bush et al, 2001., Howel et al, 2003). There is a current gap in literature in regard to the general public who are living in areas with high levels of traffic related air pollution. All participants within the research lived within an Air Quality Management Area therefore they live in areas with levels of nitrogen dioxide which have exceeded or are likely to exceed the levels set out in legislation. These are the members of the public that are exposed to the highest residential levels in Northern Ireland yet the results indicated that many of the respondents seemed unaware of the levels of air pollution. When respondents were asked to rate the air pollution in their area 18% of the respondents rated the air pollution as bad or very bad. It is important that people are aware of air pollution levels so they can make informed decisions. On a high air pollution day an informed choice would be not to run or cycle as increases breathing rate and can lead to greater inhalation of pollutants. The respondents' level of knowledge about air pollution and concern were also low. Knowledge and concern are discussed in further detail in **Section 6.2.2.4**.

The results indicated that although people are aware of traffic in their area they do not associate it with air pollution. Traffic congestion was selected as one of the top concerns of residents in their area yet air pollution did not feature in the top 3. This

indicates that residents are aware of the traffic but not the impact which it is having on air pollution in the area. It is likely that concern about traffic congestion is due to increased journey time or noise rather than air pollution which to the public is not causing an immediate visible impact. Previous research (Smallbone, 2012., Cisneros et al, 2017) indicated that the public were aware of the main sources of air pollution and particularly the sources of urban air pollution. The most frequently identified source was traffic (Smallbone, 2012). However, the results from the questionnaire completed in Study 1 indicate that awareness of air pollution and its sources in Northern Ireland may be lower. The residents rating of air quality was compared with the measured level of Nitrogen Dioxide from study 2. As the level of Nitrogen Dioxide increased, the participants were more likely to rate the air quality in their area positively. This indicates a lack of awareness among residents living in air quality management areas about the levels of air pollution which they are exposed to.

Air pollution levels are difficult to determine as they are often 'invisible' and this may be one of the reasons why awareness of air pollution was found to be low. Previous research (Bickerstaff and Walker,2001., Smallbone, 2012) found that the most common method of identifying air pollution was the worsening of symptoms of those with respiratory or cardiovascular symptoms. This was followed by identifying air pollution visually or from the odour it produced. The people questioned may be thinking of when high levels of air pollution produced a smog or haze however air pollution levels can be high without any visual signs. In addition, technology has increased within vehicles reducing the odour and smoke which would have previously been emitted. Greater education is needed for the public to understand the sources of air pollution and that exposure to high levels of air pollution which impact on health can be invisible. People find it difficult to understand something which they cannot see. Air pollution levels need to be made more visible. Currently real time monitors are made to blend into the environment however making them more visible could increase public awareness. Displaying the levels recorded in public places along with a simple 'traffic light' interpretation scheme. These measures may help to increase public awareness of traffic related air pollution. Techniques to increase awareness are discussed in greater detail in **Section 6.6**.

The above information demonstrated that those who are most exposed in Northern Ireland are unaware of the levels they are exposed to on a daily basis. More needs to be done to highlight to residents within Air Quality Management Areas about their level of exposure. If residents are unaware of exposure they are not taking measures to protect themselves such as reducing window opening during rush hour traffic. Future interventions should at first focus on increasing the awareness of people living within Air Quality Management Areas as these are the areas identified with the highest residential exposure. The low level of awareness about the levels of air pollution could be due to complacency. Residents who have lived in the area for a long period of time may be used to the levels and therefore not consider them to be high. The low level of awareness about air pollution in their area could also be due to the 'neighbourhood halo effect' (Mcboyle, 1972). This effect is seen when residents are reluctant to attribute poor environmental problems to their area. Residents who are less satisfied with their area in general are more likely to negatively rate the air pollution having a 'negative halo effect' (Bikerstaff and Walker, 2001). These findings indicate that there needs to be information actively communicated to residents living in areas with levels of air pollution which exceed the objectives. Education and awareness need to be considered as a vital role in reducing air pollution levels rather than solely focusing on the legal requirements of monitoring and report writing.

A low number of respondents could correctly identify what an air quality management area was. The most frequently selected option was, 'an area where you are not allowed to burn coal.' This indicates a low level of awareness of what the main source of air pollution in their area is. In addition, it indicates a low level of understanding and knowledge about what an air quality management area is. This is further demonstrated when analysis indicated that those respondents who knew their home was in an air quality management area were less concerned about air pollution in their area. Previous research has focused on the public's awareness of the health impact from exposure to air pollution (Wakefield et al, 2001., Bickerstaff and Walker, 2001., Howel et al, 2003., Van den Elshout, 2008., Smallbone, 2010). The public's knowledge of where levels of air pollution are high and what an air

quality management area is has not been previously investigated. These research gaps were investigated within Study 1. Research on the awareness of air pollution is of importance because of the role it can have in understanding behaviour. Wang et al (2016) comments that achieving a high level of public participation depends on the public's awareness of the issues. Taking this into consideration, the effective communication of traffic related air pollution needs take a more prominent role in air quality management. For public change to occur, awareness of traffic related air pollution needs to be increased. Previous research on awareness of the public in regard to the actions taken by local government under Local Air Quality Management is low therefore this research addresses a current gap in literature.

6.2.1 Participants' concern about traffic related air pollution

To obtain an understanding of participants concern about air pollution in their community the questionnaire asked residents to rate their top 3 concerns. It was evident that in comparison to other concerns in the community, air pollution was not rated as a high concern. The top rated concerns were those which could be identified through one of the senses such as dog fouling and noise. Traffic congestion was the most frequently rated concern yet air pollution was not rated as a top concern. This indicates that people do not associate traffic with air pollution but rather the immediate effects such as increased journey time or noise. This is similar to research conducted in California which found that when asked to rate 7 issues respondents were more concerned about wider issues such as unemployment, crime and obesity rather than air pollution (Cisneros et al, 2017).

When respondents were specifically asked about air pollution the concern expressed was still low. Previous research has focused on concern from residents who live in close proximity to industrial sources of air pollution therefore there was a need to consider proximity to traffic as a source. In addition, other studies have considered environmental concern on wider basis by including other environmental issues such as illegal dumping and water quality. Current literature focuses on the general term 'environmental concern.' Dunlap and Jones (2002, p485) define environmental concern as, 'the degree to which people are aware of problems regarding the environment, their support of efforts to solve such problems and a willingness to

contribute personally to their solution.' Residential concern about traffic related air pollution for those living in designated air quality management area was unknown. The findings of the research on concern are discussed along with the relevant literature.

For the majority of respondents' air pollution was not considered as one of their top three concerns in their area. The concerns which scored the highest were those which could be identified using one of the senses. For example, traffic congestion and dog fouling can be seen, and noise disturbance can be heard. Air pollution cannot be seen, heard or smelt therefore this maybe a reason why it was not considered a top concern for the residents. Traffic congestion was a frequently selected concern, but air pollution was not. This indicates that the residents are aware of the high traffic volume near their home but do not consider the impact which it is having on the environment around their home. The Northern Ireland Statistics and Research Agency (NISRA) conducted a survey in 2015/16 which asked participants to rate their top 3 environmental concerns. The most frequently selected environmental issue was illegal dumping (37%) followed by pollution in rivers (30%), litter and climate change (25%). Traffic congestion was the fourth most commonly selected concern about the environment. Exhaust emission and urban smog was selected by 17% of the participants when they were surveyed n 2015/16. The same survey was completed in 2003/04 when 35% of the respondents selected exhaust emissions and urban smog as a concern (DAERA,2017). This indicates that the level of concern about traffic related air pollution among the general population has fallen. The research completed the Department of Agriculture, Environment and Rural Affairs also indicates that traffic congestion is a concern among Northern Ireland residents but that the wider impact of the traffic (e.g. exhaust emissions) is not considered by the respondents.

Understanding concern for air pollution is important due to the increasing evidence on the impact which public concern can have in addressing environmental problems. There are several ways which public concern can help in reducing the human impact on the environment. For example, when the public are more concerned about an environmental issue, the greater the likelihood it will be included on the political

agenda and as a priority for government (Liu and Mu, 2016). If the residents in air quality management areas in Northern Ireland where more concerned about the impact which traffic related air pollution is having on their health and well- being this may lead to greater action being taken. Concern about air pollution among residents and commuters in London has increased in recent years and it is now one of the priorities stated by the Lord Mayor. The mayor has doubled the funding available to support the reduction of air pollution in the city (Greater London Authority, 2017). Understanding public concern and then increasing the level concern for an environmental issue can lead to behaviour change.

The residents who were surveyed within the research are living in areas of Northern Ireland with the highest level of residential traffic related air pollution exposure. As stated above the results indicated that there was a low level of concern. This contrasts with current literature which found that members of the public living in areas with a high environmental risk are more likely to have a higher level of concern (Brody et al, 2008). This is further shown by study completed in China which found that residents living in areas with high levels of air pollution where more likely to be concerned (Zheng et al, 2013). In China, the effects of air pollution can be more visible with regular smogs therefore this may result in the residents being more aware and therefore more concerned.

The area where a person lived and their level of concern was significant. Residents living in Dungiven were the most concerned about the air pollution levels in their area. This was the area with the second highest measured nitrogen dioxide levels and the location where there was there is the least distance from the road to the property façade. Furthermore, the road has a high percentage of HGV traffic. The residents may have been more concerned because of the ability to identify other effects such as noise level. The influence of education level and income was not considered within the research because of the amount of literature currently available on environmental injustice.

6.2.3 Resident knowledge of the health impact of air pollution

Analysis of the questionnaire results indicated that there is a high level of awareness among participants about the impact of exposure to traffic related air pollution and respiratory illnesses. However, awareness of other health impacts such as diabetes, stroke or cardiovascular illnesses is lower. Previous research has identified that among the public there is a lack of awareness about the impact which air pollution can have on health (Wakefield et al 2001; Bickerstaff and Walker, 2001). This research was completed over a decade ago. Since its completion there have been revisions to the air pollution information available to the public and more recently increased coverage within the media therefore more recent research on public knowledge was required. Furthermore, previous research did not identify the personal factors which may influence a person's knowledge. When respondents were asked which health conditions were affected by traffic related air pollution there was a low level of knowledge. Those who were able to correctly identify a higher number of associated health conditions were more concerned about air pollution. This was further illustrated when the respondents who strongly agreed that air pollution affects health were also more concerned about air pollution in their area. This indicates that as the knowledge about the impact of air pollution increases, so does concern. Concern about an issue is often a predecessor to action therefore for changes to occur the public should be made more aware of the impact of air pollution. Research needs to be completed on the best method of communicating information on the health impact of air pollution. This may increase public concern about exposure to air pollution and encourage change.

Overall a greater number of people were aware of the impact of exposure to traffic related air pollution on respiratory illness compared to a lower level of knowledge about cardiovascular illnesses. People may associate air pollution with respiratory illnesses by linking breathing in air pollutants to the lungs but do not consider the wider impact. Greater publicity of the impact on other health conditions needs to be completed. The communication of air pollution information is discussed further in **Section 6.6**.

In 2012, research conducted by Smallbone found that participants who had a respiratory or cardiovascular illness were more aware about the health effects of exposure to air pollution. This was similar to results in this research which found that the greater number of health conditions a person had the more concerned they were about the air pollution in their area. This result indicates that those who are more vulnerable to the effects of air pollution due to having an existing health conditions have a greater concern. This may be due to having experienced increased symptoms during high pollution days or receiving advice from medical professionals.

6.2.2 Exposure to Nitrogen Dioxide and Health Impact

As the level of nitrogen dioxide increased there was an increase in the number of people with asthma and hypertension. There is currently extensive evidence on the impact which exposure to traffic related air pollution can have on health. A detailed review of the current literature on air pollution and health was completed in **Chapter 3**. Although there is scientific evidence on the potential impact of air pollution, the number of people living in air quality management areas in Northern Ireland with health conditions is unknown. The research found that the higher the level of nitrogen dioxide, the greater the number of respondents with asthma. Asthma UK (2017) have stated that 1 in 10 people in Northern Ireland are currently being treated for asthma. The current evidence on the health impact of traffic related air pollution agrees that air pollution can aggravate asthma symptoms and some researchers have also found it can contribute to the development of asthma in children (Guatnieri and Balmes, 2010., Gasana, 2012., Khreis et al, 2017). The association between asthma and air pollution has been a long established and a large evidence base exists (Guatnieri and Balmes, 2010., Gasana,2012., Anderson et al, 2013., Favarato et al, 2014., Deng et al, 2016., Khreis et al, 2017). There is a lot of evidence which has analysed existing data sets with existing monitoring results or estimated air pollution levels. This research has linked measured air pollution levels with diagnosed asthma. In addition, the number of residents in air quality management areas with health conditions was previously unknown.

A correlation was also found with the number of residents with hypertension and the level of nitrogen dioxide. Although an association was found it should be viewed with

caution. There are many other causes of hypertension including smoking, stress, obesity, lack of physical activity and age (NHS, 2016). Further research should take into consideration these factors. However other research has been completed which has linked exposure to both nitrogen dioxide and particulate matter to hypertension (Cai et al, 2016., Fuks et al, 2014., Yin et al, 2015., Wu et al, 2016., Chan et al, 2015). Yin et al (2017) measured indoor and outdoor levels at different micro environments and found a positive association with the levels of traffic related air pollution and the number of residents with hypertension.

None of the other illnesses were found to be associated with the level of nitrogen dioxide. This research did not fully investigate the health impact due to the number of confounding factors which need to be considered. The main aim of this research was not to investigate the health impact of air pollution in Northern Ireland but to consider it as a secondary aspect. On reflection to fully consider the health impact, a number of factors should have been considered. The research did consider age, gender, smoking status and other health conditions. Socio-economic status including education level and household income has been identified in recent research as an influential factor in whether a person is more vulnerable to the effects of air pollution (Hajat et al, 2015., Cakmak et al, 2016). This factor was not included within the research due to the current amount of reliable information available therefore was not considered necessary to include.

6.3 Indoor and Outdoor Nitrogen Dioxide Levels

As the level of outdoor nitrogen dioxide increased, the level of indoor nitrogen dioxide also increased. Four of the seven monitoring locations exceeded the objective set for ambient air quality. The indoor levels recorded were much lower than the outdoor levels however there is currently no guideline level for safe indoor exposure. The majority of literature on traffic related air pollution focuses on the impact on ambient air quality especially in relation to identifying health effects (Karakatsani et al, 2010., Skene et al, 2010., Takabku et al, 2011., Villeneuve et al, 2012., Liu et al, 2012., Gallagher et al, 2013., Jai et al, 2016., Rodriguez et al, 2016). In relation to indoor levels of air pollution, the current literature focuses on the

impact of cooking and heating sources on the indoor levels of air pollution. The impact of outdoor nitrogen dioxide from traffic on indoor levels in the residential setting is a current gap in literature. To address this existing gap in literature, measurements were taken both on the outside façade of the properties and in one road facing room indoors at residential properties. The results indicated that outdoor air quality was found to impact on indoor air quality. Areas with high levels of ambient nitrogen dioxide, also had higher indoor levels of nitrogen dioxide. This is in agreement with previous studies which have found outdoor levels of particulate matter to impact upon indoor levels (Chen et al, 2012., Meadow et al, 2014., Fung et al, 2014., Meier et al, 2015). Indoor levels were higher in the summer at almost all properties. One reason for this increase in levels was an increase in the number of hours the windows were opened per day. There is currently no legally binding limit for indoor air quality therefore it is difficult to determine if the levels are higher than recommended. There are indoor air quality guidelines produced by the World Health Organisation however these focus on emissions from household fuel combustion. Greater consideration should be given to the impact of traffic related emissions on indoor air pollution and an exposure limit should be made. The majority of previous research on indoor air quality focuses on indoor/outdoor ratio or levels from combustion within the home. The research has not specifically focused on identifying indoor levels at which health effects are found.

The research found that the participants were spending a large proportion of their day at their home. There was greater variation in time spent at home during the week which may be due to different work patterns. At the weekend there was less of a variation, with people spending more time at home. On average people were spending twenty hours at home at the weekend, this indicates that residential exposure should be an important consideration. The questionnaires were completed during the winter months which may have caused the time spent at home to be longer than if completed during the summer months. Although Air Quality Management Areas have residential housing, the time spent at the properties is mainly spent indoors. The research indicates that the majority of time is spent indoors yet the main focus of legislation and air quality management is on ambient

air pollution. Consideration needs to be given to other locations where the public are likely to spend a greater amount of time outdoors.

The indoor levels of nitrogen dioxide ranged from 5µg to 30µg. Previous research which measured indoor levels has varied. For example, a study in London found a small difference in the indoor levels of nitrogen dioxide from 3µg m^{-3} to 9µg m^{-3} (Kornartit et al, 2010). The results are similar to this research as both have found low levels of nitrogen dioxide. There are other studies which have found a greater range in indoor levels and found the levels to be higher than the outdoor levels (Schembari et al, 2013). For example, research completed in Barcelona ranged from 14µg m^{-3} to 117µg m^{-3} (Schembari et al, 2013). However, there are several factors which may have influenced these levels. Firstly, due to the warm temperatures the properties may have their windows open for longer periods or may have air conditioning units. The study did not require monitors to be placed away from other indoor sources such as cookers and boilers therefore these sources may have influenced the levels.

This research is in agreement with previous literature that measuring both indoor and outdoor levels of air pollution provides a more accurate estimation of exposure (HEI, 2015., Kornartit et al, 2010., Stroh et al,2012., Demirel et al, 2014). Previous research has found that indoor levels are more closely linked to personal exposure to air pollution (Valero et al, 2009., Demirel et al, 2014). The indoor monitors were placed in an upstairs room to reduce the influence of other factors such as cooking. This is in agreement with Meier et al (2015) who advised that monitors are placed in unoccupied rooms to reduce the influence of indoor sources.

6.3.1 Outdoor Levels of Nitrogen Dioxide

There was a wide variation in the outdoor levels of nitrogen dioxide between each of the locations. All locations were selected because they were Air Quality Management Areas therefore levels were expected to be over the 40µg m^{-3} limit set in legislation. In two of the locations, Armagh and the Upper Newtownards Road in Belfast, the measured levels in both winter and summer were considerably lower than the target limit therefore questioning their requirement to be designated as air quality management areas. One factor which could have affected the level of nitrogen dioxide in both these locations is the distance to the road. Both locations

had the highest average distance from the roadside therefore other properties in the area could be exposed to higher levels. The results were compared with data from the automatic monitoring stations in both locations which were also recording considerably lower levels of nitrogen dioxide than the target limit.

Fifteen of the thirty houses included within the research exceeded the objective for ambient nitrogen dioxide. This indicates that half of the research participants are exposed to levels are of air pollution higher than recommended in the World Health Organisation guidelines. It is also evident that is some areas there is a level of caution applied by local councils who have declared air quality management areas. However, it is evident that the 2010 objective of 40µg m^{-3} for nitrogen dioxide levels in Northern Ireland is still not being met. Even though levels may be lower than other cities, the levels in Northern Ireland according the World Health Organisation guidelines are likely to impact upon health. There are also various other studies which have found health effects under the recommended limits (Yoriguiji et al, 2013., Eze et al, 2013., Eze et al, 2014., Beelan et al, 2014., Lee et al, 2015., Dijkema et al, 2016., Bowatte et al, 2017). This indicates that even the areas within this research which had levels lower than the objective could be experiencing health effects.

The highest level of measured nitrogen dioxide in both winter and summer was found on Canal Street in Newry. This location is a street canyon which impacts upon the dispersion of pollutants. The tall buildings on each side of the street hinder the dispersion and recirculation of air pollution therefore increasing exposure to those living or working in the area. Street canyons are often used when investigating traffic related air pollution (Zhang et al, 2012., Rokowska et al, 2014., Sayegh et al, 2016., Fu et al, 2017., Karra et al, 2017). It has been estimated that when a street canyon and an open road have the same traffic levels, the street canyons air pollution levels can be up to ten times higher than the level in a street canyon (Rokowska et al, 2014). The evidence in relation to street canyons is consistent and strong therefore in developing countries where cities are still being designed and built, the street canyon should be avoided due to its impact on the dispersion of air pollution.

There was a wide range in the measured levels of nitrogen dioxide across the different locations ranging from 12µg m^{-3} - 97µg m^{-3}. This was compared the levels

of nitrogen dioxide in other studies. In Switzerland the levels ranged from 7µg m^{-3} - 76µg m^{-3} (Liu et al, 2012). Furthermore, a study in Barcelona found the ambient nitrogen dioxide levels ranged from 19µg m^{-3} - 83µg m^{-3}. The comparison with these studies indicate that the range of levels within the research are similar to those within previous studies. In addition, it indicates that the range of levels in Northern Ireland are similar to other European countries. The variation in these levels have been attributed to factors including distance from the road, building height, building density and number of vehicles.

Distance from the road, temperature and season all impacted on the level of measured nitrogen dioxide. The levels of nitrogen dioxide were found to be higher in the winter rather than the summer. The current evidence on temperature and levels of air pollution is conflicting. The majority of studies agree with the results in this study and have found winter levels to be higher (Unal et al, 2011., Chan et al, 2013., Russo et al, 2014., Li et al, 2014., Patton et al, 2014., Ghafghazi et al, 2015., Dedele and Miskinyte, 2016., Sayegh et al, 2016). Higher winter levels can be caused by temperature inversions which can trap air pollution at ground level. In addition, it has been attributed to nitrogen oxide being used in the formation of ozone during the summer therefore reducing the levels of nitrogen dioxide in warmer temperatures (Sayegh et al, 2016). However, there have also been studies which state warm weather can increase the levels (Patton et al, 2014., Ghafghazi et al, 2015., Chen et al, 2013., Dedele and Miskinyte, 2016). Although temperature was found to impact on the levels of nitrogen dioxide within this research the result should be viewed with caution. In Northern Ireland, the temperatures do not reach extreme values of cold or warm temperatures. During the monitoring period, the average winter temperature was 6˚C and the average summer temperature was 16˚C. Previous research on temperature has focused on locations which have extreme temperature changes (Qin et al, 2017., Hsu et al, 2017).

Within the research the distance from the road ranged from 2 metres to 27 metres. The further the house from the road, the lower the measured level of nitrogen dioxide at the façade of the property. The results indicated a strong correlation between distance from the road and the level of nitrogen dioxide. Any house located

over 12 metres from the road, the measured level of nitrogen dioxide was below the objective. A greater reduction in levels was found when houses were located at over 20 metres from the kerb. Previous research has identified the distance which is required for the levels of traffic related air pollution to fall to background levels (Su et al, 2015., Patton et al, 2014., HEI, 2010) however to focus on public health, the level at which it falls to objective level is important. This distance which pollutants require to reduce to objective level should be incorporated into planning procedures. To reduce the level of exposure new buildings should be located at least 12 metres from the kerb. This would reduce personal exposure and allow for the dispersion of pollutants. All research which measures nitrogen dioxide should consider the influence of distance, temperature and seasonal differences.

There is a large proportion of research on traffic related air pollution which relies on estimates of residential exposure from models (Stroh et al,2012., Jerrett et al, 2013., Regettli et al, 2015., Shekarrizfard et al, 2016., Tong et al, 2016., Dimitroulopoulou et al, 2017) or readings from a nearby automatic monitoring station (Rodríguez et al, 2016., Ozkaynak et al, 2013). Using the levels from one monitoring station does not consider the spatial and temporal variability of air pollution. The range of measured levels in this research demonstrates that estimating exposure in these ways can lead to errors. The levels within one location varied therefore using one estimated level is inaccurate of personal exposure. Furthermore, the indoor levels were lower than ambient levels. Using indoor levels is a more accurate representation of exposure if the research participants spend the majority of time indoors. This should be given consideration when designing future research that focuses on the impact of exposure to air pollution.

6.3.2 Personal Exposure to Nitrogen Dioxide

Personal exposure to nitrogen dioxide was another aspect that was considered within the research. The personal level of nitrogen dioxide ranged from 9µg m^{-3} to 23µg m^{-3}. There is currently no guideline for indoor air pollution levels therefore it is difficult to determine if the levels recorded are protective of health. The number of participants for this aspect of the research was low and therefore only 2 locations were covered. The monitors used were passive badges and were exposed for one

week. The participants were asked to complete a time activity diary. For the three results gained, all personal levels were closer to the indoor levels of measured nitrogen dioxide rather than the outdoor level. This indicates that indoor levels may be more representative and the measurement of outdoor levels. This is in agreement with current literature which has stated a greater correlation with indoor levels (Schembarri et al, 2013., Kornartit et al, 2010). The personal monitoring part of the research produced limited results however from the limitations identified, recommendations for future research on personal exposure to air pollution can be made. For conclusions to be drawn and links between activities and exposure, real time air pollution measurements need to be made. One of the results had significantly higher levels of nitrogen dioxide than the other two measurements. An assumption was made that this could be due to the participant cooking on one day for four hours. Previous research has identified the number of hours cooking especially on a gas cooker to be influential on the measured level of nitrogen dioxide (Kornartit et al, 2010., Schembari et al, 2013., Meier et al, 2015., Dedele and Miskinyte, 2016). A real time monitor would allow the reason for the peak in levels to be accurately identified. Furthermore, as the indoor and outdoor levels of air pollution were measured at the residential property the participants were asked to wear the badge on while at the house and to remover when in other microenvironments. On reflection, the participants should have worn the badge at all times to gain information on their overall exposure. However due to the low number of participants the suggestion of only wearing it at home was suggested to increase the number of participants. To fully investigate the relationship between indoor, outdoor and personal levels monitors would need to be placed in the microenvironment were the participants spend the most time for example work and home. There has been previous research which has completed this.

6.4 Evaluation of Local Air Quality Management

The results from this research have indicated that local air quality management has failed to deliver the reductions in traffic related air pollution which is needed to comply with legislation. This is demonstrated through the monitoring results in Study

2 and the opinions gathered from the interviews in Study 3. The main reasons for this failure have been identified as the lack of stakeholder commitment, repetitive action plans and lack of public engagement. The monitored levels of nitrogen dioxide from Study 2 indicated that there still needs to be action taken in Northern Ireland to reduce traffic related air pollution. There seems to be no easy solution to traffic related air pollution as Local Air Quality Management has been in place for over a decade with little progress being made.

In Northern Ireland there are currently 22 Air Quality Management Areas declared due to traffic. There are some Air Quality Management Areas which consist of a whole city while others encompass houses at one side of a street. The interviews were used to determine the decision-making process for the declaration of the areas. There were several different methods used to determine the boundaries of the AQMA's for example modelling, road layout and monitoring. Modelling allows from the air pollution levels to be estimated by inputting influencing factors such as road gradient, wind direction and other built environment features. One area which encompassed the whole city stated their AQMA was aligned with the smoke control zones. This rationale does not seem to consider the exposure to traffic related air pollution. There needs to be clear guidance produced which outlines approved methods for determining appropriate boundaries. There is a lack of previous research which has focused on the boundary setting process. However, from the descriptions and maps of air quality management areas throughout the United Kingdom it is evident that there is variation throughout.

The production of action plans on an annual basis was seen as a repetitive task by the respondents which in relation to traffic has led to few reductions in the levels. When an air quality management area is declared, the local council are required to produce an action plan. The progress of implementing the actions are reviewed annually. The success of this process in reducing levels of traffic related air pollution was seen as limited by the majority of respondents. There is often little progress made in within a year and councils stated that it was often a 'copy and paste' process from the year before. The actions mentioned in reports, if achieved often will not lead to dramatic changes in the area. For example, a number of the councils have

stated changing the council's diesel van fleet to electric powered. Although this action provides good civic leadership, the council's fleet alone will not lead to great changes in the air pollution levels. This indicates that the current system of reporting is inadequate at producing changes in the levels of air pollution from traffic. Similar views have been found in other research which has stated the reporting to be excessive (In House Policy Consultants, 2010). This has been taken into consideration and reporting has been streamlined in England.

All local councils complete air pollution monitoring either using diffusion tubes or automatic monitoring stations. Changes in road layouts and the addition of new developments in areas can change the distribution of traffic and therefore the traffic levels. The monitoring locations should therefore be reviewed on a periodic basis. There is currently no legal requirement to review monitoring locations or provide rationales for the chosen monitoring locations. It was evident through the interviews that local councils are aware that reviewing the locations is necessary, the reality of implementing this is different. Many emphasised that their sole work load is not just focused on air pollution therefore reactive work often takes priority. Within air pollution, completing the legal requirements takes priority.

6.4.1 Strengths and Weaknesses of Local Air Quality Management

There are only 2 traffic related air quality management areas which have successfully reduced the air pollution levels allowing the AQMA to be revoked (DAERA,2017). This part of the research was necessary to identify future improvements to the system which would help local councils meet the limits set out in legislation. The strengths and weakness of the application of local air quality management in Northern Ireland were identified.

6.4.1.1 Strengths

The process has been successful in increasing the knowledge of professionals about the levels of air pollution in their district. Without the legal obligation to monitor, the levels air pollution and therefore the impact would remain unknown. The process has successfully identified the 'hot spot' areas. Previous research also found that without the current legal requirement to monitor and assess, the financial

support which is currently available would not have been received (Longhurst et al, 2009).

Positive feedback was also received on local air quality management's focus on receptors. Areas can only be declared if there is residential exposure. This has also been a point which received some criticism as others believed other exposure should be considered. This research demonstrated that in Northern Ireland few hours are spent outdoors at residential properties therefore the impact on indoor air quality should be considered. Previous research had not identified the focus on receptors as a strength of local air quality management. The majority of previous research has failed to identify the strengths of the current system.

In contrast to current literature, respondents felt there was political support for reducing air pollution in Northern Ireland. Within the draft programme for government there is a target for reducing air pollution levels. The inclusion of this target may support the finding that in Northern Ireland there is political awareness of the issue. Respondents stated that there was generally support locally for air quality issues from local councillors. However, one respondent in the research did feel that potentially the good will of politicians in relation to air pollution was only at face value. It was felt that the politicians did not fully understand the extent of change which would be required to make significant differences in reducing the air pollution levels. Introducing schemes such as congestion charging, increasing vehicles excise duty and increasing fuel tax are all methods which could substantially reduce private car use and therefore air pollution levels. However, in Northern Ireland where private car use is high, it would be an unpopular decision among the public and therefore there are likely to be few politicians who would encourage these policies. Similar studies (Jones and Longhurst, 2010., Campbell and Green, 1996., Olowoporoku et al, 2010) conducted in England found that politics could hinder improvement to air pollution. These previous studies found that politicians favour economic development and often consider the short-term advantages of increasing employment rather than the long- term impact of increased traffic in the area. It is evident there is more which the government could be doing to decrease the levels of traffic related air pollution. They have recently been taken to High Court by Client

Earth for failing to meet the limit values stated within European Legislation (Williams et al, 2016). The United Kingdom's membership to the European Union has had a positive impact on various environmental issues including air pollution. European legislation made it a legal requirement for all member states to monitor and assess air pollution in their area and for member states to achieve air quality objectives. The air quality objectives were created to protect the health of European citizens. The legally binding limits meant the UK government were taken to court for failing to meet the requirements. Without air quality objectives, there would be no ability to judge air pollution levels or for the public to be aware of what a safe exposure level is (Harrison, 2017). In addition, the Euro Standards were created to reduce emissions from vehicles. The European Commission has been proactive in creating policies to reduce air pollution. With the terms of the United Kingdom's exit from the European Union currently being decided upon there is concern that less stringent environmental standards may be adopted. Without the pressure from European regulations, the United Kingdom could fall behind (New Scientist, 2016). Currently there are plans for a 'Great Repeal Bill' which will transpose EU law into legislation for the United Kingdom post Brexit therefore current air quality objectives should continue to apply. Concern has been raised about how the government will be held accountable for failing to meet air pollution targets when they are no longer members of the European Union (Client Earth, 2016). Even if the European Objectives are adopted, there will no longer be the threat of infringement fines from the EU therefore the need to comply will be lost (Harrison, 2017). There is still uncertainty regarding the terms of Brexit and whether the United Kingdom will exit the European Union but remain within the European Economic Area (EEA). Countries such as Norway and Iceland are members of the EEA which means they still have to meet the EU legislation on environmental issues (Parkes, 2016). Brexit brings challenges to managing air pollution but could also bring opportunities for greater environmental achievements. This research has highlighted the impact which traffic related air pollution is making in Northern Ireland. It is vital that air quality is considered as a priority post Brexit to protect public health.

The Environmental Audit Committee (2016) produced a report entitled, 'The Future of the Natural Environment after the EU Referendum'. Within the report seven recommendations are given to the government and associated departments such as DAERA. The report states that a new Environmental Protection Act needs be legislated during the Article 50 negotiations to ensure a continuation of current environmental standards. It states that introducing this new Act before the leaving would reduce the risk of 'zombie legislation.' This a term used to describe EU law that would be transposed into UK law but never updated and eventually forgotten about. There will be challenges in transposing certain EU laws and new governance will have to be established therefore progress needs to begin now. The European Union also provides some environmental funding therefore the government also needs to commit resources. Within the UK government manifesto one of the objectives they have stated is to, "be the first generation to leave the environment in a better state than it found it" (Environmental Audit Committee, 2016). For this to be a reality, air pollution and other environmental issues need to be a priority in Brexit.

There were few strengths found through the research. The only area which all respondents agreed on was the success of local air quality management on increasing the knowledge of the levels of air pollution among professionals. Other strengths included political support and focus on receptors. The lack of positive comments in the research indicates that there is a need for change.

6.4.1.2. Weaknesses

There were positives of the current system found but there was also agreement that changes needed to be made for improvements in air quality to be seen. Reporting was mentioned in all the interviews as an area requiring change. The lack of progress made in implementing measures from the action plan and reducing air pollution levels can lead to frustration. Suggested actions often do not have the financial backing required for them to go forward. When improvements are not seen from the work, frustration with the lack of progress is felt. This point needs to be considered when developing action plans. Actions stated need to realistic and achievable. There should be increased emphasis on reports being honest and attainable rather suggesting actions just to meet the criteria of the report. Previous

research has not identified this aspect but has stated that the system requires excessive reporting (In House Policy Consultants, 2010). England, Scotland and Wales have all moved towards action planning to aid in the reducing the burden of reporting. Rather than producing Detailed Assessments, Action Plans and Progress Reports, Local Authorities will now have to produce only one annual report. These reports may also be joint report between neighbouring Local Authorities. Although this may reduce reporting burden, it is not addressing the unrealistic and unachievable actions which are stated. In addition, the requirement to monitor and report on certain Air Quality Objectives has been removed. Particulate matter and Nitrogen Dioxide must be monitored however those which the pollutants which are no longer of national concern do not have to be monitored or included within the report (Welsh Government,2017). This may reduce the reporting required and also allow for resources such as time and monitoring budgets to be focused on the pollutants of most concern.

The funding councils received from the Department of Agriculture, Environment and Rural Affairs (DAERA) has been decreased. Although this has not affected the air pollution monitoring in the majority of councils, one council has had to reduce the number of automatic monitoring stations. One respondent commented that the lack of funding indicates the lack of government commitment to reducing air pollution levels. Local Councils do not have an adequate budget for the actions which are required to reduce traffic related air pollution. Lack of funding is an issue across all Local Authorities in the United Kingdom as a recent consultation in Wales found that those implementing the legislation felt their work was under funded (Welsh Government, 2017). In Northern Ireland, further funding is needed to implement road schemes which would reduce traffic congestion. The schemes which need to be completed for air pollution to be significantly reduced are larger than local councils implement. Parliament need to introduce nationwide policies to force behaviour change. Efficient public transport systems need to be in place, higher fuel taxation and congestion charging. These harder measures are required to give momentum to the management of air pollution. When the public see the

government taking serious action to reduce air pollution this in turn may increase their awareness of the seriousness of the issue.

Another resource concern for the respondents was the lack of time which is available to be devoted to air pollution work. For all of the respondents' air pollution was only one area of their work load. The time which they would like to spend on air pollution is often not possible due to the amount of other responsibilities which they have. The available time to spend on air pollution is often only to get the necessary reports completed. The respondents also felt there is an under estimation of the amount of time it takes to complete their responsibilities in relation to air pollution. More proactive work which involves promoting and engaging with the public about air pollution does not happen due to the lack of dedicated time to air pollution work. This is an aspect of air quality management which needs to be considered for improvements to be made.

A large number of stakeholders were identified through the interviews. Their commitment to improving local air quality divided opinion. It was evident that the information that was needed for the completion of progress reports was sent however anything above this was limited. Meetings which have been organised by councils with the relevant stakeholders have led to little progress due to the wrong level of personnel sent. Often those attending the meetings have no decision-making powers therefore cannot give answers on the availability of money for schemes. The stakeholders have no obligation to consider how their actions impact on air pollution levels therefore it is not their priority. Stakeholders can often require persuasion from local councils to take action. Air pollution needs to be embedding within some of these organisations however when it is not within their policy context they have motivation to consider it. Stakeholder commitment has been investigated in research completed in England (Hayes, 2009., Olowoporoku et al, 2012) and found to be an area requiring further development. Previous research found that consultation with both internal and external stakeholders can be problematic. It has been found to be a 'tick box' exercise which is done to complete the legal requirement but provides little progression in meeting air quality objectives (Dorfman et al, 2006). Jones and Longhurst (2010) found that the lack of interaction

between local authorities and other stakeholders has be attributed to the poor communication between the groups. The frequency and type of information communicated were stated as reasons why communication between the groups was not successful. Air pollution cannot be reduced through the action of one department or council. A multi-disciplinary approach is required with commitment from all to achieve a reduction in levels.

6.5 Future Improvement

It is evident that local air quality management has achieved some success since its inception in 2002. However, in recent years, improvements in air pollution levels have been limited. The legislation initially focused on the identification of air pollution through monitoring was appropriate however a review is required for further reductions in traffic related air pollution to be made. There is a need for change in how managing air pollution is approached for long lasting change to be made. Scotland and Wales have already begun the process of changing their approach to air pollution management. The changes made to their management approach addresses some of the issues which were identified in this research about the current Local Air Quality Management Regime in Northern Ireland. Within the interviews, those who are delivering the current system were asked their thoughts on how Northern Ireland should update their approach to managing air pollution.

The need for change has been identified through this research and with the United Kingdom currently going through Brexit preceding's it is an opportunity to change the approach to managing air pollution. There are several non-government organisations who have proposed that a new Clean Air Act should be created which will introduce a more stringent approach to tackling air pollution (Tilling and Raby, 2017). Brexit should be used as an opportunity to increase environmental standards within the United Kingdom rather than for the environment to be forgotten about.

6.5.1 Wider Reduction Strategy

There was agreement on the need for a 'wider reduction strategy' within the research. This requires a move away from focusing on small hot spot areas and instead encouraging the reduction of air pollution in all areas as air pollution has no

boundaries. Currently action is only required when the Air Quality Objectives set in legislation are breached yet there are benefits to reducing air pollution levels in all locations. Respondents were in favour of reducing the focus from air pollution limits to improvements in health and the environment. This mirrors one of the techniques suggested in Scotland's new Air Quality Strategy- 'Cleaner Air for Scotland, A Road to a Healthier Future' (Scottish Government, 2015). Although the wider reduction strategy plans to create greater improvements in air pollution, there still needs to emphasis on the areas which expose local residents to higher levels of air pollution. Focus on these areas should not be abandoned.

6.5.2. Shared Responsibility

One of the key changes which was mentioned by all councils was the need for 'shared responsibility.' It was felt that sole responsibility for delivering air pollution improvements should not be left to local councils alone. They can facilitate the discussions, produce the reports and monitor the levels but they cannot force other agencies to make changes. Greater responsibility should be placed on other agencies. A multi -agency, multi- disciplinary approach is required. Greater engagement between different departments is required. Traffic related air pollution will not be solved through the work of one department. The actions within the Clean Air for Scotland Strategy involve highlighting air pollution to other agencies and integrating air pollution into other policies. For example, ensuring that planning policies work in conjunction with the principles outlined in the Cleaner Air for Scotland strategy. There is also emphasis for the NHS to have greater involvement and for air pollution to be included in their policies. The focus on health continues as they aim to meet the World Health Organisation (WHO) Guidelines for PM2.5 and PM10 which are more protective of health (Scottish Government, 2015). If the Government and the public fully understood the health implications of exposure to traffic related air pollution, there would be a greater urgency to take action.

6.5.3. Technological Advancements

One respondent stated that reducing traffic related air pollution is a 'waiting game.' The term 'waiting game' referring to the technological advances in car emissions is hoped to reduce the levels of air pollution in the future. Furthermore, it refers to the

expected increase in electric vehicles which is anticipated to reduce the levels of air pollution from traffic. Technological advances have solved previous air pollution problems such as the introduction of gas heating to reduce the use of coal burning. The government recently announced in their new Air Quality Strategy that the sale of all diesel and petrol vehicles will be banned by 2040 (DEFRA, 2017). This plan is similar to those announced in France under the Paris climate accord to ban sales by 2040 (New Scientist, 2017). Norway has the highest number of registered electric vehicles in the world and it plans in 2025 to only sell electric or plug in hybrid vehicles (Norwegian EV, 2017). The main source of fuel for vehicles would then be electricity. There have been many critics who have stated the plans are unachievable. Within Europe, 0.6% of new car registrations were for all electric vehicles (International Council for Clean Transportation, 2017). There is a lot of change required for all new registrations to be electric. Currently the infrastructure is not in place, with few charging points available. In addition, it is questionable whether the electricity supply would be able to cope with increased demand required to fuel all vehicles, especially at peak times (National Grid., 2017). The government plans are ambitious but there is doubt in regard to whether they are achievable. However, there are also critics who state 2040 is too late. An economist, Tony Seba (2017), has predicted that the change to electric vehicles will happen much quicker than the 2040 deadline by stating; '*Banning sales of diesel and gasoline vehicles by 2040 is a bit like banning sales of horses for road transportation by 2040: there won't be any to ban*' (Seba, 2017).

In addition, previous attempts have been made to reduce emissions from vehicles through technology. Euro 6 was introduced as the standard which would deliver major reductions in road emissions. The vehicle manufacturers have failed to produce real world driving reductions therefore no noticeable reduction in air pollution levels have been found (International Council for Clean Transportation, 2014). For technological advances to be successful they needed to be complimented with behaviour change from the public including a reduction in car usage.

6.5.4 Air Quality Management in Other Countries

In Perth Australia, a thirty-year Air Quality Management Plan was produced in 2000. Similar to the United Kingdom, air quality is monitored and plans produced. There are however practical initiatives run in conjunction with the reporting. For example, a Clean Run programme has been developed which tests vehicles emissions at the roadside and provides free vehicle health checks. Furthermore, it provides the public the opportunity to report smoky vehicles (Perth Air Quality Co-Ordinating Committee, 2016). In the United States of America, a similar management system exists to that within the United Kingdom. If an area is found to be exceeding the guidelines it is designated as a 'Non-Attainment Area' (Gulia et al, 2015). There is little available evidence on what actions are being taken by other countries to reduce the levels of traffic related air pollution. There is evidence of monitoring and reporting of results however information on methods of reducing traffic related air pollution is minimal. There needs to be a platform developed where best practice techniques and innovative methods of reducing air pollution levels can be shared.

6.6 Communication of Air Pollution Information

6.6.1 Current Provision of air quality information

The members of the public interviewed stated that there needs to be more information on air pollution levels. However local councils stated the information is available but rarely is the information requested. EC Directive 2003/4/EC states that the public must have access to environmental information. Under this legislation the information must be freely available, easily understood and accessible to all members of the community. The directive states that information should be disseminated to the public to increase awareness and therefore help to improve the environment. Where possible the information is to be communicated using electronic technology (European Commission, 2003). This European legislation was transposed in law in the United Kingdom through the Environmental Information Regulations 2004 (Information Commissioners Office, 2017). The main method of communicating air quality information in Northern Ireland is through the airqualityni website. This website contains real time information on the levels of air pollution from the automatic monitoring stations. The website also has information on the

current legislation on air pollution, the impact of air pollution on health and the environment and on Local Air Quality Management (Riacrdo Environment and Energy, 2017). The effectiveness of the website and other information sources at delivering air quality information in Northern Ireland has not been previously reviewed in current literature. This was assessed within the research by interviewing local residents and local councils. There is concern that the focus of local councils is meeting the legal requirements for communicating air pollution information rather than producing information which engages with the local public.

The residents were asked who they would contact if they were concerned about air pollution in their area and under half of the respondents identified their local council. A similar study conducted in England found that the most common responses of where to get further information on air pollution was the Environment Agency or the Local Authority (Smallbone, 2012). When information is produced in the future, it should clearly state who to contact for further information.

For a wider reduction in air pollution to be achieved, behaviour change from the public is required. The majority of the local councils interviewed felt that the amount of information available to the public is adequate as they are not inundated with requests. Some did believe that there needs to be a change in what information is available. Previous research (Bikerstaff et al,2001., Howell et al, 2003) found that those with health conditions were uncertain about where they could find more information on air pollution and if found how they could apply to improve their health. Shooter and Brimblescombe (2008) stated there was a need for information which is easy for the public to understand and easy to find. Since these previous reviews the information available to the public has changed therefore the awareness of air pollution information was considered within this research.

The interviews with local residents in this research revealed that the public are unaware of what information is available or who to contact in relation to air pollution. All residents stated that they would like more information on air pollution and suggested the formats that they would most likely use. A website was on the most commonly suggested media. A similar study completed in 2012 found that a

website was the most favoured option for receiving air pollution information (Smallbone, 2012).

The airqualityni website is currently the main method of communicating air pollution information yet the majority of the residents are unaware of its existence. The website needs to be supported by other medias such as billboards or radio advertisements to make the public aware that it is available. A review of the website should be completed to consider if the information included is appropriate. The website includes information on the levels, the legislation and current reports completed. This information is technical and perhaps more suitable for people with an existing knowledge of air pollution. Information to increase awareness would be more appropriate. It was expected that participants may have suggested the use of social media including Facebook and Twitter for updates on air pollution information however it was suggested by a low number of participants. This may have been due to the age of the participants and on reflection age should have been recorded. Social media may be seen as a tool for communicating with friends and relatives rather than a tool for learning. The use and impact of social media is an aspect which could explored in more depth.

One of the current methods of communicating air pollution information is through the air quality index. The index uses a 10-point scale which is divided into four bands. The bands are colour coded with green indicating low levels of air pollution and purple indicating very high levels. Each band has accompanying health information and advice on if any behaviour change is required (DAERA, 2017). The air quality index was not mentioned by any of the residents interviewed therefore indicating that there is little awareness of its existence. Research completed in 2012 (Smallbone) also found that people were unaware of the index as a source of information. The research found that people want concise information which is jargon free.

Raising public awareness and knowledge of air pollution is a difficult task compared to raising awareness for other environmental concerns which are more visible. For example, people can see and experience the impact that flooding can have on an area. It is difficult to draw comparisons from other environmental campaigns due to

the unique invisibility of the problem. In addition, consideration was given to campaigns for other road issues such as road safety and their success in reducing road deaths. However, for the public, the impact of road safety such as the number of collisions on a road is more tangible than the number of deaths from air pollution due to the number of confounding factors. Therefore, the most appropriate comparison for the communication of air pollution information was an evaluation of how other countries communicate the information.

6.6.2 Communication of air pollution information in other countries

The communication of information about air pollution has been more successful in other countries and even in other parts of the United Kingdom. There several examples which can be seen as 'best practice' within the field of air pollution information. One of these is London. Currently in London, air pollution levels are communicated by the website London Air and the associated app. In addition, they actively use social media including twitter and Facebook (London Air, 2017). There are also other organisations in London which support the communication of information including 'Breathe London' which provides practical information on reducing personal exposure to traffic related air pollution. This includes an online route planner to reduce exposure (Breathe London, 2017). In Scotland, there is an increasing amount of available information. There is currently a campaign being developed with different advertising platforms being considered. There are also plans to collect data on public awareness of air pollution to inform the development of new communication methods (Scottish Government, 2015). There are many other countries which produce similar information for the public on air pollution levels as Northern Ireland which mainly relies on the Air Quality NI website. All European countries are displaying the monitored levels of air pollution on websites as required by law. This is also similar to current practices in Australia and the United States of America (Gulia et al, 2015). One of the main failings within the current system in Northern Ireland is the requirement for the public to actively look for the information. It is evident from this research that the majority of residents are unaware of air pollution as an issue so would not actively try to obtain further information. This technique is more effective with visible problems such as dog

fouling. In relation to air pollution, communicating information needs to be more actively displayed within communities.

6.6.3 Recommendations for future communication strategies

Councils thought that the information which is currently provided is adequate, with many agreeing that they are not inundated with requests on air pollution therefore assuming that it is not needed. This approach to providing information is reactive whereas a more proactive approach is required. Information should be readily available in the public domain encouraging the public to consider the impact of their actions on air pollution. In addition, it would allow for greater public choice. If the public had a greater awareness of areas which had higher levels of air pollution they could make informed decisions. For example, a member of the public could decide whether to go for a run (which increases breathing rate and therefore greater exposure) in an area which is known to have high levels or go to an area with lower levels. This would protect health which should be the main aim of reducing air pollution levels. If the public are not made aware of the levels, they cannot make an informed choice to change their actions to reduce exposure such as closing windows. The current text alert system is focused on those who have respiratory illnesses which can be aggravated by high pollution levels, but this information should be made known to everybody. The results from Study 1 illustrate there is a low awareness among the public about air pollution being an issue, therefore greater effort is required to inform them. Cleaner Air for Scotland the new strategy for reducing air pollution in Scotland has communication as one of its priorities. One of the methods which they are using is a National Awareness Campaign. Various different medias are planned to be used including advertising methods, citizen science and conducting research. Three key messages have been chosen and key audiences (Scottish Government, 2015). Local Councils suggested a campaign as a potential communication method in Northern Ireland.

The automatic monitoring stations in Northern Ireland are often painted black or green to avoid attention being drawn to them and to reduce the risk of vandalism. Management of air pollution is currently done in the background with few people aware of what is currently being to protect them. When local residents were asked

who they would contact, the majority did not know it was their local council. One respondent from a local council interview suggested that monitoring stations should instead be used as a tool for raising awareness about the air pollution levels. The respondent stated that in Latvia monitoring stations display the real time air pollution levels. Digital readouts accompanied with a 'traffic light' indication of the air pollution levels would allow the public to make an informed choice and increase awareness of levels. Furthermore, electronic street panels have been used to display air pollution levels and give information (Oltra and Sala, 2015). The panels display information to the people who are using the areas affected by high air pollution levels. In California, a flag program to highlight the air pollution levels has been developed. Public buildings such as schools and government buildings display different coloured flags to represent the air quality in the area (Cisneros et al, 2017). The success of the program in schools was reviewed. It was considered a positive intervention as the schools took practical steps to reducing exposure when levels were high for example exercise outdoors was avoided (Shendell et al, 2007). The effectiveness of the system with the general public has not been reviewed.

Learning about air pollution needs to begin from an early age. This was suggested by one respondent who felt that education needed to begin at school. For children to understand the impact of their actions on the environment around them and simple actions which can be taken to reduce levels. An educational programme has been launched in Glasgow by the Scottish Environmental Agency (SEPA,2017) to highlight the impact of air pollution. The exhibition explains the need for clean air and the simple actions which individuals can take to play their part in reducing air pollution. The real time levels from monitoring stations are displayed and a model city allows users to experience the impact of different transport modes on traffic congestion and emissions of air pollution. This exhibit is accompanied with online resources for schools to use (SEPA,2015). There are resources to use for all stages including primary, secondary geography and science. There is also the opportunity for schools to request an air sensor to monitor the pollution levels at their school. The Cleaner Air for Scotland Strategy also aims to produce a national campaign to raise awareness

of air pollution to all members of the public. Similar education strategies are required in Northern Ireland to improve public awareness.

The results of this study into air pollution information and communication indicates that a change in the current information is required. The public are unaware of the levels of air pollution and where to get further information. The local councils are providing the information required by European legislation but public engagement with the information seems to be low. Consideration should be given on the communication method used and how to promote the information available. Although it is evident that information is available, the results indicate that it is unlikely that people will search for it themselves. To overcome this challenge, information needs to be communicated to people on platforms which they are already reading or using for example local newspapers or billboards. Further research should be completed with the end user to identify the most suitable methods. A guide on effective communication methods should be developed taking into consideration best practice from other sectors.

6.7 Limitations of the Research

Each method of data collection has merits and limitations. This was taken into consideration when designing the empirical data collection. A mixed method approach was considered the most appropriate methodology for the research. This approach allows for the limitations of one method to be overcome by combining methods. The limitations of the research are discussed below.

6.7.1. Study 1

Several of the questions within the survey used Likert scales asking residents to rate their concern or awareness about air pollution. The questions were chosen as a suitable method due to their wide use throughout previous research. The main limitation of this method is the interpretation of the scale. To overcome this limitation, the questionnaires were tested among a group of academics and participants. This allowed for any inconsistent responses to be identified. Furthermore, the questionnaires were completed face to face which allowed for additional explanation if required.

For Study 1 a second limitation is the potential impact of non- response. Those who did respond to the survey may have had greater concerns about air pollution therefore motivating them to participate. Those who did not participate may have had different views therefore non-response may have introduced bias into the results. This was considered in the design of the research and a number of actions were put in place to limit the number of non-responses. Firstly, the questionnaires were completed by going door to door. This allowed the researcher to fully explain the research and answer any concerns which the respondent might have therefore encouraging participation. To increase participation in the questionnaire and reduce demographic bias, houses were visited at different times of the day including day time, evening and weekend.

The questionnaire in study 1 asked respondents if they had any health conditions. The respondents were asked to state their age and if they or any member of their household smoked. On reflection other considerations such as economic status should have been included. There are many factors which contribute to health conditions therefore the results of the health questionnaire are only indicative. There are many previous studies which have used a similar methodology including the following: Furthermore, other research has been completed using existing data sets and modelled air pollution levels which is may not accurately represent the air pollution levels.

6.7.2. Study 2

In Study 2 the number of participants for the monitoring of nitrogen dioxide was limited. The number of participants in each area ranged from 3 to 7 depending on the willingness of the residents. A criteria was set for who could participate in the research to increase the reliability of results. This included excluding any property which had any smokers and any property more than 200 metres from the automatic monitoring station or road. This excluded a large number of properties however was necessary for reliability. The 200 metres was used due to the evidence from the Health Effects Institute (2010) on the dispersion of nitrogen dioxide.

Diffusion tubes were considered the most appropriate method of measuring the nitrogen dioxide level and have been used in many previous studies (Karakatsani et al, 2010., Beelan et al, 2013., Skene et al, 2010., Liu et al, 2012). The advantages were discussed in the methodology. However, the diffusion tubes only give an average for the monitoring period. It would have been interesting to identify the peaks and troughs. This would have allowed for the identification of how many hours in a day the levels are above the objective. However, the diffusion tubes were compared to automatic monitors in the area to increase the reliability.

The study focused on the impact of nitrogen dioxide from traffic. There is increasing evidence on the health impact of particulate matter which is also emitted through vehicle emissions. If further resources were available, the impact of particulate matter could have been investigated as well. There are currently no low-cost monitors for particulate matter which can be placed indoor and outdoor.

The research took into consideration the impact of distance from the road on the levels of nitrogen dioxide. The average traffic levels were used from the latest Transport NI report. The temperature levels were from the Met Office statistics. The impact of these factors could have been investigated in greater detail if there was greater resource availability. A traffic count could have been completed in each of the locations during the monitoring period and a weather station could have measured the temperature, wind and rain. This would have allowed for a more accurate indication of the impact of these factors in each of the locations. The use of centralised monitoring systems for weather and traffic counts have been used in the majority of previous studies (Namdeo et al, 2011., Chen et al, 2016., Woodword et al, 2016). This validates it as an appropriate method.

When initially designing the research, personal monitoring was included to investigate the link between indoor, outdoor and personal exposure to nitrogen dioxide. Difficulty was found in finding research participants who were willing to complete all three types of monitoring. The personal monitoring therefore only had 3 participants therefore this was considered when drawing conclusions from the research. The data does not sufficiently represent the population living in AQMAs in Northern Ireland. The results should be seen as indicative rather than conclusive.

An explanation was given to each of the residents who agreed to the indoor and outdoor monitoring of what would be required during the monitoring. The passive badges were chosen to encourage participation as they were easily attached to clothing and did not require an electric supply. The low cost also meant that a greater number could be included. Passive badges have also been used in previous studies (Schembari et al, 2013). The personal monitoring was to give an indication of how the indoor and outdoor levels compared with personal exposure. The low levels of participation meant the results could not be compared with the indoor and outdoor levels. Participation rates in previous studies which have required the respondent to wear a monitor have been low (Steinle et al, 2015., Dons et al, 2011). For example, Dons et al (2011) has eight research participants. There are also studies which have used university staff and students which has increased participation rates (Liu et al, 2015). The use of incentives could be considered to encourage participation. Personal monitoring which gives real time measurements and includes a detailed time activity diary is an area for future research within Northern Ireland.

6.7.3. Study 3

The number of residents from Air Quality Management Areas who participated in the interviews was low. The residents had previously participated in Study 1 and 2 therefore their previous time commitment to the research may have affected their willingness to participate further. The 22 interviews completed are not representative of the whole population therefore the results should be viewed with consideration to this. On reflection the initial questionnaire in Study 1 should have included a section on public information which would have allowed for a greater number of responses to be gathered and therefore been more representative of the general population. Further research could be conducted in this area

Interviews were chosen as the most appropriate method for gathering information from local councils as in-depth information on the effectiveness of the current procedures and future improvements was required. The sample was limited to local councils within Northern Ireland. This was felt most appropriate as the previous studies had been restricted to England and Scotland. Northern Ireland is unique due to its devolved administration and travel patterns therefore was important to

consider. The research could be replicated to produce results for the whole of the United Kingdom.

6.7.4 Resource Limitations

Resource limitations could have potentially impacted upon the sample size within the research. Greater time would have allowed for a larger number of homes to be included within the research. All aspects of the research were conducted in Air Quality Management Areas with an automatic monitoring station. If there was greater time, the questionnaire in Study 1 could have been extended to all Air Quality Management Areas declared due to traffic in Northern Ireland. In addition, if additional resources were available the research could have been extended to the Republic of Ireland to investigate air pollution from an all-Ireland approach.

The monitoring of Nitrogen Dioxide had to be restricted due to financial constraints. The diffusion tubes used had many advantages however they only give an average level for the exposure period. Monitors which give real time levels of air pollution allow for peaks to be identified and a greater understanding of how long people are exposed to these levels.

Although the research had some limitations, there has still been a contribution to knowledge and understanding. The methodological limitations can be used to influence the design of future research.

6.8 Summary

This chapter thematically discussed the key findings of the research including the respondents' awareness of traffic related air pollution in their area and the effectiveness of local air quality management in Northern Ireland.

Research questions were outlined at the beginning of the research. Below is a description of how the research has answered each of the questions.

RQ1- What is the level of understanding, concern and awareness of air pollution among residents living in Air Quality Management Areas?

•The residents' level of understanding, concern and awareness was assessed through the questionnaire. There was a low level of awareness among residents about the level of nitrogen dioxide in their area.

RQ2- What are the current levels of roadside nitrogen dioxide in Northern Ireland and how do they impact on indoor levels of air pollution?

•The indoor and outdoor levels of nitrogen dioxide were measured in 7 Air Quality Management Areas in Northern Ireland. As the outdoor level of Nitrogen Dioxide increased, the indoor level increased.

RQ3- Is the current Local Air Quality Management regime successful in reducing the level of traffic related air pollution?

- Environmental Health Officers from all Local Councils were interviewed regarding the current Local Air Quality Management Regime. The system was seen as successful in identifying areas with high levels of air pollution but the success of reduction has been limited.

RQ4- What improvements can be made to the current air quality management regime?

- The interviews identified measures which could be introduced to improve local air quality management. Measures introduced in other countries were reviewed. The wider reduction strategy used by the Scottish Government was favoured by the respondents.

The overall key findings from the research are stated below;

- Residents living in Air Quality Management Areas are unaware of air pollution as a problem in their area
- Areas with high levels of nitrogen dioxide have increased number of residents with asthma and hypertension
- Residents in Northern Ireland are being exposed to ambient levels of nitrogen dioxide which do not meet the requirements set in EU legislation

- Majority of time is spent indoors therefore this must be considered when assessing exposure. As levels of outdoor air pollution increase, indoor levels also increase.
- Local Air Quality Management has identified areas with high levels of air pollution
- Current action plans are an ineffective tool in reducing air pollution levels
- For traffic related air pollution to be reduced a multi-disciplinary approach is required
- Greater priority needs to be given to informing the public about traffic related air pollution using a method which communicates the message in a non-technical and relevant way

These findings are presented in light of the current political situation in the United Kingdom. Air pollution needs to be a key environment issue discussed during Brexit talks and legislation needs to be in place to protect public health. Progress has been made in identifying air pollution hotspots, but continued action is required. The air that people breathe is not a choice but a right. The public have the right to breathe clean air which will not affect their health.

Chapter 7 presents the main conclusions of the research. Furthermore, the policy implications of the research are presented along with suggestions for future research. The unique contribution of the research to the field of traffic related air pollution is also presented.

Chapter 7- Conclusions, Implications and Recommendations

7.1 Introduction

Each year the number of registered vehicles in Northern Ireland increases, along with increases in the number of miles travelled by car. It is expected that this trend of car dependency will continue to increase in the future. An increasing number of vehicles leads to an increase in the emissions from vehicles. The health impact of exposure to traffic related air pollution is an extensive and increasing knowledge base. There is strong evidence linking exposure to traffic related air pollutants with respiratory and cardiovascular illnesses. Public understanding and knowledge of the health implications of exposure to emissions from vehicles is one of the key areas to begin the process of implementing change.

Taking into consideration the current gaps in literature, the aim of the research was developed. The research was designed to meet the following aim;

To identify public awareness and perception of air pollution and to establish the indoor and outdoor levels of nitrogen dioxide from traffic in Northern Ireland. The research also aims to review the current Local Air Quality Management regime and make recommendations for future practice.

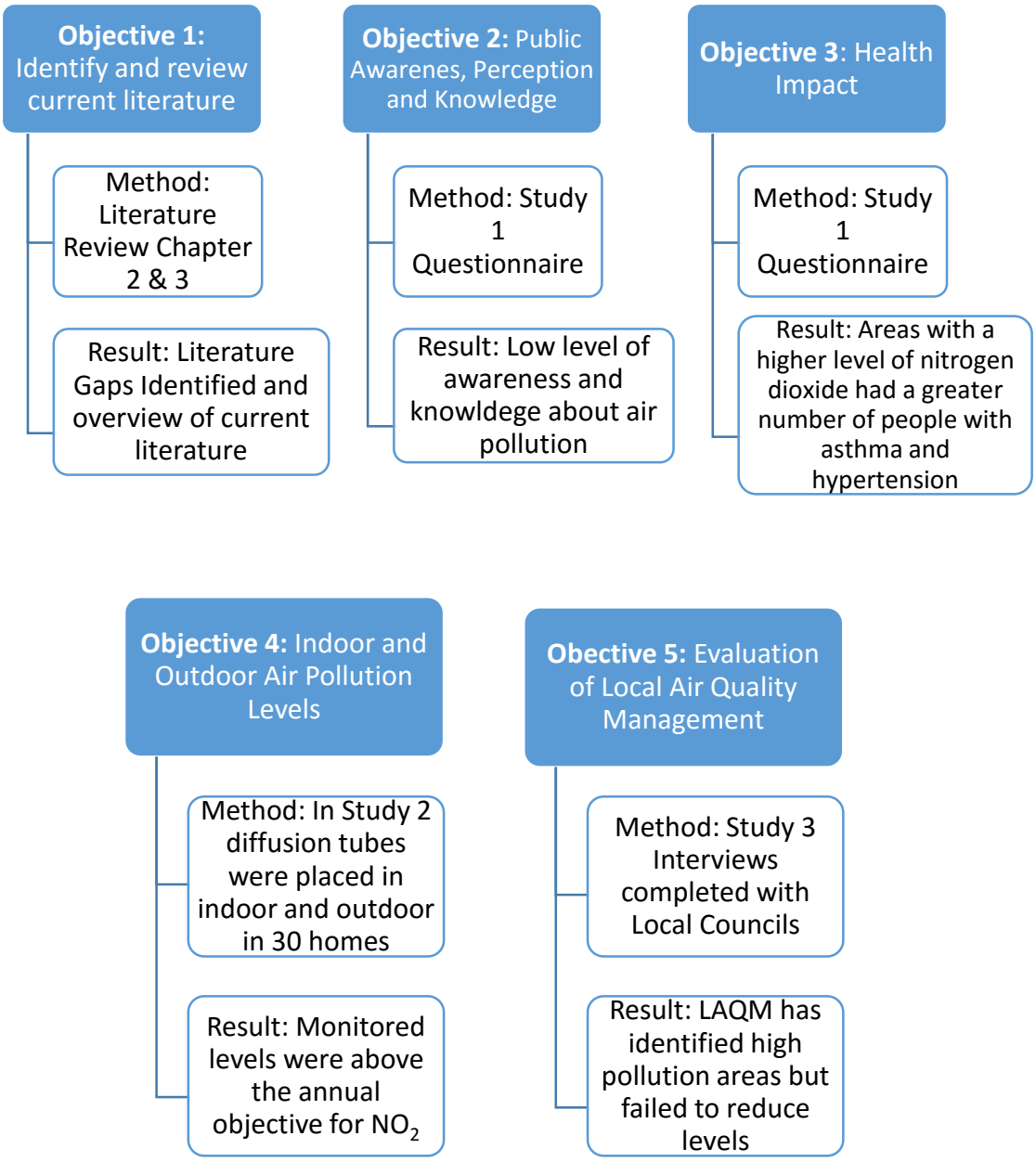
This chapter summarises the key findings of the research and the implications for the future of local air quality management. The chapter begins by highlighting how each of the objectives of the research were met and emphasises the key findings. The contribution of the research to the field of air pollution is stated along with the implications for both policy and practice. Areas which require further investigation are highlighted as areas for future work at the conclusion of the chapter.

7.2 Research Aims and Objectives

The research consisted of the three stages including a critical review of the existing evidence on traffic related air pollution, the empirical data collection and finally the discussion of the findings in light of current literature. Objectives were set for each stage of the research. This section will discuss how each of the objectives were met

within the research. A visual representation of how each of the objectives were met can be seen in **Figure 26**.

Figure 26: Research Overview



Objective 1: To identify and review the current evidence on the health effects associated with exposure to air pollution, in particular the pollutants associated with traffic

Objective 1 was completed during the theoretical research stage. A critical literature review was completed to identify the current evidence on the health impact of air pollution. The review specifically focused on traffic related air pollution with nitrogen dioxide and particulate matter the main focus. The findings of the review were used to develop the questionnaire. The review found the strongest evidence was in relation to respiratory and cardiovascular illnesses. It was evident that the majority of research was conducted using existing monitoring sets or modelled data therefore research measuring exposure levels was required.

A further critical literature review was completed which focused on the following areas; awareness and knowledge of air pollution, indoor and outdoor levels of traffic related air pollution and a review of the current local air quality management regime. These literature reviews provided an extensive overview of the current research on traffic related air pollution. The majority of previous research focused on outdoor air quality. Although this is where the source is emitted, the amount of time spent outside is low. There was also a lack of previous research completed in Northern Ireland. The importance of local air quality studies was identified through previous research due to the variability of air pollution dispersion due to natural and built environment factors. The travel patterns and government structure are also unique attributes to Northern Ireland which affect the management of air pollution.

Objective 2: To identify public perception, awareness and knowledge of traffic related air pollution

Objective 2 was met during the empirical data collection stage. In Study 1 a questionnaire was administered to residents living in Air Quality Management Areas. The questionnaire focused on the residents concern about air pollution, their perception of air pollution and their knowledge of its impact. The findings indicate a low level of awareness among the participants about air pollution in their area and their exposure. The majority of participants did not consider air pollution to be of high concern in their area. As the level of air pollution increased the participants level of concern for air pollution decreased. This indicates a lack of awareness about exposure to traffic related air pollution and in particular among those who are exposed to the highest levels.

Objective 3: To establish the health impact of living near a road that exceeds air quality guidelines for traffic related air pollutants

Objective 3 was met through the empirical data collection. The questionnaire in Study 1 asked participants if they had any medically diagnosed health problems. The age of the person, the number of years they had the condition and the symptoms they experience were recorded. Participants were also asked if their symptoms had improved or declined since living in their current property. Each condition was statistically analysed with the measured levels of nitrogen dioxide. As the level of nitrogen dioxide increased there was an increase the number of participants with asthma and hypertension.

Objective 4: To establish the current levels of traffic related air pollution, indoor and outdoor, on several roads in Northern Ireland

Objective 3 was met through the empirical data collection stage. Study 2 measured the level of nitrogen dioxide indoor and outdoor in 30 homes across seven locations in Northern Ireland. The findings indicated that as the outdoor level of nitrogen dioxide increased the indoor level also increased. There were several areas were the levels of nitrogen dioxide were higher than the objectives within legislation. The areas which exceeded includes Glengormley, Newry, Ormeau Road Belfast and Stockmans Lane Belfast. All these areas were above the legally binding limit of 40µg m^{-3}. There is currently no guidance in relation to indoor nitrogen levels from traffic therefore it is difficult to assess whether exposure levels are harmful to health.

Objective 5: To evaluate the Local Air Quality Management Regime and identify measures for future development

Objective 5 was met through the empirical data collection. In study 3, interviews were conducted with the all local authorities which had air quality management areas which were declared due to traffic. The interviews identified the strengths and weaknesses of the current system and measures which could be introduced to improve the effectiveness of the current system. The interviews also focused on the information sources currently available for the public on traffic related air pollution. To complement the local authority interviews, resident interviews were completed.

The interviews identified if the residents were aware of who to contact in relation to air pollution and what information was currently available to them. The majority of residents were unaware of any sources of air pollution information available to them and there was some confusion on who to contact if they were concerned about air pollution levels in their area. The most frequently suggested method identified by the residents as a method of communication which they would use was a website. The airqualityni website already exists indicating that greater publicity is required to make the public aware of where to find the information.

In addition to the research aim and objectives, research questions were designed. These questions were developed after identifying the gaps in literature from the critical literature review. The findings of the research have addressed each of these questions.

Research Question 1: What is the level of understanding, concern and awareness of air pollution among residents living in Air Quality Management Areas?

Research Question 2: What are the current levels of roadside nitrogen dioxide in Northern Ireland and how do they impact on indoor levels of air pollution?

Research Question 3: Is the current Local Air Quality Management regime successful in reducing the level of traffic related air pollution?

Research Question 4: What improvements can be made to the current air quality management regime?

The answers to each of the research questions stated above are evident through the key findings. The key findings are stated in **Section 7.3**.

7.3 Key Findings

The research has identified several findings which will be useful for future practice and for the development of policy in regard to traffic related air pollution. Each of the key findings are discussed individually below.

Key Finding 1: As knowledge about air pollution increases, concern about air pollution also increases

Key Finding 1 found that as the respondent's knowledge about the health effects associated with exposure to air pollution increased, the respondents were more likely to be concerned about air pollution in their area. This indicates that greater knowledge leads to greater concern.

This key finding is of importance for those developing future air pollution reduction interventions. As public knowledge about the impact of air pollution increases, the greater public concern there would be for reducing air pollution levels. Greater concern has the potential to change people's attitude towards changing their habits. For example, if the infrastructure and public transport networks are in place, a person who is concerned about air pollution may reduce their private car usage or change to an electric vehicle. For changes to be made in relation to car dependency there needs to be greater public awareness of the benefits and also the essential infrastructure in place.

Key Finding 2: Residents in Air Quality Management Areas are unaware of air pollution as an issue in their area

Respondents were asked about their opinion of the air quality in their area. All the surveys were completed in AQMAs where air pollution levels have been identified as being over the legal limit. There were few respondents who stated the air pollution in their area as bad.

Air pollution is an invisible problem and is difficult for the public to identify. This finding indicates that there needs to be more effective communication methods to inform the public. When informed, people can make choices such as not opening their windows during rush hour traffic in an attempt to reduce their personal exposure.

Key Finding 3: Areas with high levels of nitrogen dioxide have increased number of residents with asthma and hypertension

The respondents were asked if they had any medically diagnosed illnesses. A link was found between the level of nitrogen dioxide and the number of individuals in each area with asthma and hypertension. This research is in line with current evidence which has a found a link between asthma and hypertension. This research has indicated that there is a health impact of living in an area which does not meet the current objectives for nitrogen dioxide.

Key Finding 4: Residents in Northern Ireland are being exposed to ambient levels of nitrogen dioxide which do not meet the requirements set in EU legislation

The monitoring results indicate that there are residential areas in Northern Ireland which are still not meeting the annual objective of nitrogen dioxide which was to be met by 2010. This indicates that the public are being exposed to levels which have the potential to be impact on their health and well-being. Clean air is a right and not a choice. The people living in these areas do not have the choice to not breathe in the air pollution in their area. Seven years past the deadline of meeting the 2010 annual objective for nitrogen dioxide the government need to start dedicating resources and finance to providing the infrastructure to reduce the nitrogen dioxide levels in Northern Ireland.

Key Finding 5: As the level of outdoor nitrogen dioxide increased, the indoor level also increased.

The impact of outdoor pollution on indoor levels is of key importance for those living in Northern Ireland. The research participants were spending on average 17 hours a day at home therefore it is a significant place of exposure. There are currently no guidelines on a safe exposure level for indoor nitrogen dioxide therefore it is difficult to determine the toxicity of the exposure. With the majority of time spent indoors, greater priority needs to be given to the impact which outdoor air pollution is having on indoor air quality.

Key Finding 6: Local Air Quality Management had failed to reduce emissions from traffic

There were several strengths of local air quality management particularly in relation to the identification of hot spot areas. Professionals now have a greater knowledge about the levels of air pollution across Northern Ireland. However, only a couple of AQMAs which have been declared due to traffic have been revoked. The same system has been in place from 2002 with little review or change. With little progress being made, a need for change was identified from the interviews.

A consultation has been recently launched for a new Air Quality Strategy for Northern Ireland. Scotland and Wales have already started to implement the actions in their new strategies for air pollution. The findings from this research have identified the areas where key changes are required which are specific to Northern Ireland and therefore should be taken into consideration in the development of the strategy.

Key Finding 7: There is a need for greater public engagement

The results indicated that people are unaware of the levels of air pollution they are exposed to, have little knowledge about the health effects and are not aware that they live in an AQMA. They were also unaware of what information was currently available on traffic related air pollution. All these results indicate that there needs to be greater engagement with the public about air pollution.

Air pollution levels will not be reduced through local authorities writing action plans. The actions need to be realistic, achievable and communicated to the public. Change requires public involvement. The interviews identified that the public are not aware of information available on the levels of air pollution in their area. For greater public engagement in reducing air pollution levels, local authorities need to be actively promoting the benefits of reducing air pollution and making information readily available.

7.4 Contribution to Knowledge

The research investigated various aspects of traffic related air pollution in Northern Ireland. The awareness, knowledge and perception of traffic related air pollution was investigated in Study 1. Furthermore, previous research has broadly focused on environmental concern incorporating various environmental issues such as littering or water quality however the sole purpose of this research was to investigate traffic related air pollution. Previous research had assessed the general public's knowledge of the health impact of air pollution. This research was unique due to the focus on residents living within AQMAs. People living within these areas have been identified as being exposed to levels of air pollution potentially harmful to health. Living in these areas means they may have a greater exposure period to high levels of air pollution and are therefore at greater risk to the impact than the general public. The research found there was a low level of awareness among participants about air pollution in their area.

The majority of research completed on the impact of air pollution uses existing data sets or central automatic monitoring stations to identify the level of exposure to pollutants. Using these methods does not consider the spatial and temporal variation of air pollution. In addition, the majority of previous research on traffic related air pollution has focused solely on ambient air pollution. In Northern Ireland, a large proportion of time is spent indoors therefore this was considered an important aspect to investigate. Previous research has been completed in schools and office buildings to investigate the indoor outdoor ratio of pollutants. Residential exposure is a significant exposure route therefore it was considered important aspect to consider. The research was developed by considering these gaps within previous research. In each area there were small differences between properties which demonstrates the variability of pollution. The level of indoor nitrogen dioxide was found to be correlated with the level of outdoor level of air pollution. As the outdoor level of nitrogen dioxide increased, the indoor level also increased. This indicates that outdoor air pollution has some impact on indoor air quality.

The third aspect which the research investigated was local air quality management. Previous reviews of local air quality management have been completed in England

and Scotland but have not included Northern Ireland. It is important to have an understanding of how effective the legislation is in Northern Ireland as it varies from England and Scotland by having a different transport system, a more widespread settlement pattern and a different local council hierarchy. These differences would affect the council's ability to implement changes therefore a focused review in Northern Ireland was thought to be essential. In addition, the previous reviews have focused on identifying the strengths and weaknesses of the system. The results from Study 1 found that there was a lack of awareness among the respondents about the levels of air pollution and the health impact of exposure to air pollution. From this finding, the need to investigate the current methods of communicating air pollution information was identified.

7.5 Research Implications

The findings of this research has implications for policy makers in developing future strategies and legislation. Furthermore, the practical recommendations were also identified.

Currently in the United Kingdom, there are no guidelines for indoor exposure to pollutants such as nitrogen dioxide. It is difficult to ascertain whether the levels measured within this research are acceptable. As the majority of time spent in Northern Ireland is indoors, consideration needs to be given to this exposure route. A guideline level should be developed for indoor nitrogen dioxide taking into consideration the length of exposure to indoor air. Previous guidelines have been published on the impact of indoor combustion such as open fires however the impact of outdoor pollutants need to be considered.

The research has highlighted that in Northern Ireland there are levels of traffic related air pollution higher than the legally binding objective. The current objectives are due to the United Kingdom's membership of the European Union. Article 50 has now been triggered and the United Kingdom is in the process of leaving the European Union. All current legislation is due to be transferred however an area of concern is the lack of accountability the government will have post Brexit if air quality objectives

are not met. The UK government is currently in court due to their failure to meet the European Union objectives for nitrogen dioxide. Systems need to be in place for post Brexit to ensure the government is kept accountable in relation to meeting air quality objectives. A policy needs to be developed on how air quality standards will be improved post Brexit.

The current Local Air Quality Management system needs to be updated. The current system has been effective at reducing the levels of traffic related air pollution. A system needs to focus on achievable and realistic actions. The government need to dedicate funding for the reduction of air pollution levels as many of the actions required cannot be completed with the budget of local government. In some of the areas included within this research, for lasting reductions in air pollution to be made the road infrastructure needs to be changed. Local councils do not have the authority for these changes to be made therefore greater involvement of central government is required.

DEARA have launched a consultation period for Northern Irelands Air Quality Strategy. This consultation seeks professional views on the strategy. This research provides useful evidence on the current situation on air pollution in Northern Ireland and identifies areas which would be useful for inclusion within the strategy. This key finding of this research should be considered when developing future interventions and policies in relation to traffic related air pollution in Northern Ireland.

Greater emphasis needs to be placed on the communication of air quality information. The research indicated that residents are currently unaware of what information is available. Furthermore, people are unaware of their exposure and the potential impact on health. The current approach is reactive as information is only distributed when requested. For public knowledge to be increased, information needs to be actively distributed to the public. One method which could be used is an awareness campaign to highlight the levels of air pollution. The focus should be on the areas with the highest exposure. Greater and more effective public engagement is required.

7.5.1 Key Policy Recommendations

The results of the research identified several recommendations for future policy decisions in relation to air pollution in Northern Ireland. The key recommendations are:

- Develop resources to increase public awareness of their exposure to air pollution. In particular, the main focus should be on those living in Local Air Quality Management Areas
- Update the current Local Air Quality Management Regime. Greater emphasis should be placed on the responsibilities of government departments. Furthermore, realistic and achievable reports should be produced.
- Create an air quality strategy for Northern Ireland in line with the strategies developed in Scotland and Wales

7.6 Future Research

The results of the research indicated areas where future research should focus. The literature review in Chapters 2 and 3 identified many literature gaps which could not all be addressed within this research.

Study 1 which involved the use of a quantitative questionnaire could be expanded across all air quality management areas in Northern Ireland. This would allow for a greater sample size and for more in depth information to be acquired about perception of traffic related air pollution among residents in Northern Ireland. There could be a comparison completed with the general public to identify whether the awareness and perception of those living in AQMAs is different from the general public.

In relation to the monitoring of air pollution, the study could be expanded by including the monitoring of particulate matter. There was no cost effective method available for accurately monitoring 30 homes simultaneously for particulate matter. Recent research has indicated the health impact of exposure to particulate matter therefore identifying the indoor and outdoor level would be of importance. Furthermore, the weather conditions were recorded using met office data, if

equipment was available a more accurate monitoring of local weather conditions would be beneficial. The diffusion tubes used within the research have many advantages, however they only give an average level for over the exposure period. Future research should consider the use of monitors which record real times levels. This would allow for identification of whether peaks and troughs in traffic levels result in peaks and troughs of indoor and outdoor levels of nitrogen dioxide.

The investigation into Local Air Quality Management could be expanded. The interviews could be complimented with a document analysis of current air quality action plans. In addition, a historical review could be completed to identify how effective the reports are at encouraging the implementation of reduction measures. The documents should be combined with the measured levels of nitrogen dioxide in the area. Furthermore, a review should be completed on the new air quality strategy implemented in Scotland – A road to a healthier future. This review would enable effective changes to be in the service delivery of Local Air Quality Management in England, Wales and Northern Ireland.

The literature review also identified several research gaps which could not be addressed within this research. There is a need for the health impact of air pollution to be investigated in greater detail. Biological mechanisms for the impact of the pollutants on the body need to be established to increase the reliability of the evidence. There also a need for research to determine the levels at which the health effects occur. There is a large amount of research on health but few studies have identified at what level health effects begin.

7.7 Conclusion

This research has provided empirical evidence on the impact of traffic related air pollution in Northern Ireland. The results have indicated that public awareness and concern about exposure to emissions from traffic is low and therefore is an area for future consideration. Exposure to nitrogen dioxide is impacting on the health of those living in air quality management areas particularly those with asthma. Traffic related air pollution is not only impacting on those spending time outdoors but is

infiltrating the quality of air inside. Indoor air quality needs to be considered due to the proportion of time spent indoors. Air pollution in Northern Ireland may not be at the same level of residents in larger cities but regardless of this, it is still at a level where action is required. If current travel patterns continue, levels will only continue to increase. A change in the method of air quality management is required to ensure that the residents of Northern Ireland have a place to live which promotes health and wellbeing. The air that people breathe is not a choice and therefore people have the right to breathe clean air.

References

Abhijith., Kumar., Gallagher., McNabola, Baldauf., Pila., Brudenick., 2017. Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments – A review. *Atmospheric Enviornment.* 162.pp71-86.

AEA Energy and Environment. 2008. *Diffusion Tubes for Ambient NO_2 Monitoring: Practical Guidance for Laboratories and Users.* [online]. Available from: https://laqm.defra.gov.uk/documents/0802141004_NO2_WG_PracticalGuidance_Issue1a.pdf (accessed on 5th June 2018).

Algar, O.; Pichini, S.; Basagana, X.; Puig, C.; Vall, O.; Torrent, M.; Harris, J.; Sunyer, J.; Cullinan, P. 2004. Concentrations and determinants of NO2 in homes of Ashford, UK and 23 Barcelona and Menorca, Spain. *Indoor Air.* 14.pp298-304.

Anderson,H., Favarato,R., Atkinson,R.,2013. Long term exposure to air pollution and the incidence of asthma: meta- analysis of cohort studies. *Air Quality, Atmosphere and Health.* 6.(1)pp47-56.

Anderson., Kristiansen., Klaus., Olsen., Hvidberg., Jensen., Ketzel., Loft., Sørensen. 2012. Long-term exposure to air pollution and asthma hospitalisations in older adults: a cohort study. *Journal of American Heart Association.* 43.pp320-325.

Anderson., Raaschou-Nielsen., Ketzel., Jensen., Hvidberg., Loft. 2012. Diabetes incidence and long-term exposure to air pollution: a cohort study. *Diabetes Care.* 35. Pp92-98.

Asthma UK. 2017. *Asthma Facts and Statistics*. [online]. Available from: https://www.asthma.org.uk/about/media/facts-and-statistics/ (accessed on 7th October 2017).

Aurangojeb, M. 2011. Relationship between PM10, NO2 and particle number concentration: validity of air quality controls. *Procedia Environmental Sciences*.6. pp60-69.

Auliciems, A., & Burton, I. 1967. Trends in smoke concentrations before and after the Clean AirAct of 1956. *Atmospheric Environment*. 7(11).pp1063-1070.

Awbi,H., 2015. *The future of indoor air quality in UK homes and its impact on health.* University of Reading. Reading.

Badman,H., Duncan,M., 2009. Perceptions of air pollution during the work related commute by adults in Queensland , Australia. *Atmospheric Environment*. 43(36) pp 5791-5795.

Baldauf., Thoma., Khlystov.,Isakov.,Bowker.,Long.,Snow. 2008. Impacts of noise barriers on near-road air quality. *Atmospheric Environment.* 42.pp7502-7507.

Balti., Echouffo-Tcheugui., Yako., Kengne. 2014. Air pollution and risk of type 2 diabetes mellitus: A systematic review and meta-analysis. *Diabetes Research and Clinical Practice.* 106 (2) pp161-172.

Barnes,JH., Hayes, ET., Longhurst, JWS., 2015. Has UK local government action improved local air quality? A Bristol case study. Ecology and The Environment.198. 243-254.

Barnes,JH., Hayes, ET., Chatterton,TJ., Longhurst,JWS.,2014. Air Quality Action Planning: Why do barriers to remediation in local air quality management remain? Journal of Environmental Planning and Management. 57 (5): 660-681.

Barnes, J., Hayes, E. T., Longhurst, J. and Olowoporoku, A. 2012. Air quality action planning: Barriers to remediation in local air quality management. *Air Pollution XX*. pp. 139-150.

Beattie,CL., Longhurst, JWS., Woofield, NK., 2001. Air Quality Management: Evolution of policy and practice in the UK as exemplified by the experience of English Local Government. Atmospheric Environment 35, 1479-1490.

Bertram,D., 2008. Likert Scales. [online] Available from: http://poincare.matf.bg.ac.rs/~kristina/topic-dane-likert.pdf (accessed on 12th Januray 2017).

Bell., Zanobetti., Dominici., 2013. Evidence on vulnerability and susceptibility to health risks associated with short-term exposure to particulate matter: a systematic review and meta-analysis. *American Journal of Epidemiology.* 178 (6) pp865-876.

Beelen., Raaschou-Nielsen., Stafoggia., Andersen., Weinmayr., Hoffmann. 2014. Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multicentre ESCAPE project. *The Lancet.* 383 (9919) pp785-795.

Beelen., Hoek., Vienneau., Eeftens., Dimakopoulou., Pedeli., Tsai., Kunzli., Schikowski., Macron. 2013. Development of NO_2 and NO_x land use regression models for estimating air pollution exposure in 36 study areas in Europe – The ESCAPE project. *Atmospheric Environment.* 72. Pp10-13.

Beko, G., Weschler, C.J.,Wierzbicka, A., Karottki, D.G., Toftum, J., Loft, S., Clausen, G., 2013. Ultrafine particles: exposure and source apportionment in 56 Danish homes. *Environmental Science and Technology*. 47pp 10240–10248.

Bentayeb., Wagner., Stempfelet., Zins., Goldberg., Pascal., Larrieu., Beaudeau., Cassadou., Eilstein., Filleul., Tetre., Medina. 2015. Association between long-term exposure to air pollution and mortality in France: A 25-year follow-up study. *Environmental International.* 84. Pp5-14.

Bertin,M., Chevier,C., Serrano,T., Manfort,C., Cordier,S., Viel,F., 2015. Sex specific differences in foetal growth in newborns exposed prenatally to traffic related air pollution in France. *Environmental Research.* 142. Pp680-687.

Berry., Clarke., Pajot., Hutton. 2011. Risk Perception, Health Communication, and Adaptation to the Health Impacts of Climate Change in Canada, Climate Change Adaptation in Developed Nations: From Theory To Practice. *Climate Change Adaptions in Developed Countries.* 42. Pp2015-219.

Bikkerstaff, Walker., 2001. Public Understandings of Air Pollution: The Localisation' of Environmental Risk. *Global Environmental Change*. 11.pp133-145.

Bickerstaff, K.,Walker, G. 2003. The place (s) of matter: matter out of place–public understandings of air pollution*. Progress in Human Geography*, 27(1), 45-67.

Billingsley, D., 1974/1975. Air pollution in Edinburgh. Ph.D. Thesis, University of Edinburgh, unpublished. Blacksell, M., 1972. Attitudes toward smoke control in Exeter. Paper: Man and Environment Commission Symposium, Calgary, July 24-31.

Bickerstaff, K., Walker, G.P., 1999. Clearing the smog: public responses to air quality information. *Local Environment*.

Blackman., Perret., Savory., Piquet.2015. Field and wind tunnel modelling of an idealized street canyon flow. *Atmospheric Environment.* 106.pp139-153.

Blaxter, L, Hughes, C and Tight, M (1996) How to Research, Buckingham, Open University Press.

Boogaard, H. 2012. Effects of traffic policies on air pollution and health- an intervention study. Utrecht University. Netherlands.

Bonnes., Uzzell., Carrus., Kelay. 2007. Inhabitants' and experts' assessments of environmental quality for urban sustainability. Journal of Social Issues. 63 (1). pp. 59-78.

Bonney, R., Dickinson, J.2012. *Overview of citizen science. Citizen Science: Public Participation in Environmental Research*. Cornell University Press. New York.pp19-26.

Bowatte,G., Lodge,C., Knibbs,L., Lowe,A., Erbas,B., Dennekamp,M., Mark,G., 2017. Traffic related air pollution exposure is associated with allergic sensitisation, asthma and poor lung function in middle age. *Journal of Allergy and Clinical Immunology.* 139 (1) pp122-129.

Bowatte,G.,Lodge,C., Lowe,A., Erbas,B., Perret,J., 2014. The influence of Childhood Traffic-Related Air Pollution Exposure on Asthma, Allergy and Sensitisation. A Systematic Review and a Meta-Analysis of Birth Cohort Studies. *Allergy*.

Bord., O'Connor., Fisher. 2000. In what sense does the public understand climate change? *Public Understanding of Science.* 9(3)pp205-218.

Braun, V and Clarke, V. (2006). Using Thematic Analysis in Psychology. Qualitative Research in Psychology, 3 (2): 77-101.

Brantley., Hagler., Deshmukti., Baldauf., 2014. Field assessment of the effects of roadside vegetation on near-road black carbon and particulate matter. *Science of the Total Environment.*468.pp120-129.

British Lung Foundation, 2017. *Asthma Statistics.* [online]. Available from: https://statistics.blf.org.uk/asthma (accessed on 20th June 2017).

Brody et al., 2008 Samuel D. Brody, Sammy Zahran, Arnold Vedlitz, Himanshu Grover. Examining the relationship between physical vulnerability and public perceptions of global climate change in the United States. Environ. Behav., 40 (1) (2008), pp. 72–95.

Brody, S., Peck, B.,Highfield, W.2004. Examining localized patterns of air quality perception in Texas: a spatial and statistical analysis. Risk Analysis, 24(6) pp 1561-1574.

Brook., Burnett., Dann., Cakmak., Goldberg., Fan., Wheeler. 2007. Further interpretation of the acute effect of nitrogen dioxide observed in Canadian time-series studies. *Journal of Exposure Science & Environmental Epidemiology*, 17. pp36–44.

Brunt., Barnes., Longhurst., Scally., Hayes. 2016. Local Air Quality Management policy and practice in the UK: The case for greater Public Health integration and engagement. *Environmental Science and Policy.* 58.pp 52-60.

Bowker., Baldauf., Isakov., Khlystov., Petersen. 2007. The effects of roadside structures on the transport and dispersion of ultrafine particles from highways. *Atmospheric Environment.* 41.pp8128-8139.

Bossche., Theunis., Elen., Peters., Bottledooren., De Baets. Opportunistic mobile air pollution monitoring: A Case Study with city wardens in Antwerp. *Atmospheric Environment.* 141. Pp408-421.

Breathe London. 2017. *Improving your community's health through breathing cleaner air*. [online]. Available from: http://www.breathelondon.org/ (accessed on 25th August 2017).

Brown, P., Brody, J. G., Morello-Frosch, R., Tovar, J., Zota, A. R.,Rudel, R.2012. Measuring the success of community science: The northern California household exposure study. *Environmental Health Perspectives*. 120 (3). Pp. 326.

Brunekreef B. 2007. Health effects of air pollution observed in cohort studies in Europe. Journal od Exposure Science and Environmental Epidemiology. 17.pp61-65.

Bryman, A., Cramer,D., 2011. Quantitative Data Analysis with IBM SPSS 17,18 &19. East Sussex: Rutledge.

Burns, R (2000) Introduction to Research Methods, London, Sage.

Buteau., Hatzopoulou., Crouse., Smargiassi., Burnett., Logan., Burnett., Goldberg. 2017. Comparison of spatiotemporal prediction models of daily exposure of individuals to ambient nitrogen dioxide and ozone in Montreal, Canada. *Environmental Research.* 156. Pp201-230.

Buccolieri, Salizzoni., Soulhac., Garbero., Sabatino., 2015. The breathability of compact cities. *Urban climate.* 13.pp73-93.

Bush, J., Moffatt, S., & Dunn, C. 2001. 'Even the birds round here cough': stigma, air pollution and health in Teesside. *Health & Place*, 7(1). pp47-56.

Cakmak,S., Hebbern,C., Cakmak,J., Vanos,J.,2016. The modifying effect of socio-economic status on the relationship between traffic, air pollution and respiratory health in elementary school children. *Journal of Environmental Management.*17.pp1-8.

Cai., Zhang., Ke., 2016. Associations of short-term and long-term exposure to ambient air pollutants with hypertension: a systematic review and meta-analysis. *Hypertension.*68. pp62-70.

Cai., Zhao., Liu., Xia., Zhu., Wang., Song., Kan., Zhang. 2017. Exposure to particulate air pollution during early pregnancy is associated with placental DNA methylation. *Environment International.* 607-608. Pp1103-1108.

Carey., Atkinson., Kent., van Staa., Cook., Anderson. 2013. Mortality Associations with Long-Term Exposure to Outdoor Air Pollution in a National English Cohort. *American Journal of Respiratory and Critical Care Medicine.* 187 (11) pp1226-1233.

Cao., Yang., Chen., Gu. 2011. Association between long-term exposure to outdoor air pollution and mortality in China: a cohort study. *Journal of Hazardous Materials.* 186 (2-3). Pp1594-2000.

Cambridge University Press., 2017. *Meaning of awareness.* [online]. Available from: http://dictionary.cambridge.org/dictionary/english/awareness (accessed on 10th July 2017).

Campbell., Green., 1996. Green cities, growing cities, just cities? Urban planning and the contradictions of Urban Planning. *Journal of American Planning Association.* 62. (3) pp296-312.

Capraz., Deniz., Doğan. 2017. Effects of air pollution on respiratory hospital admissions in İstanbul, Turkey, 2013 to 2015. *Chemosphere.* 181. Pp544-550.

Capraz., Efe., Deniz. 2016. Study on the association between air pollution and mortality in İstanbul, 2007–2012. *Atmospheric Pollution Research.* 7 (1) pp147-154.

CARB (2007). *Review of the California ambient air quality standard for nitrogen dioxide.* Sacramento, California Environmental Protection Agency Air Resources Board. [online]. Available From: http://www.arb.ca.gov/research/aaqs/no2-rs/no2-doc.htm#TechSuppDoc, accessed 1 March 2013. Accessed on 1st March 2016.

Carmichael,L., Lambert,C., 2011. Governance, Knowledge and sustainability. The implementation of EU directives on air quality in Southampton. Local Environment.16 (2). 181-191.

Carungno., Consonni., Randi., Catelan. Grisotto., Bertazzi., Biggeri., Baccini. 2016. Air pollution exposure, cause-specific deaths and hospitalizations in a highly polluted Italian region. *Environmental Research.* 147. Pp415-424.

Cesaroni., Badaloni., Gariazzo., Stafoggia., Sozzi.,Davoli., Forastiere. 2013. Long-term exposure to urban air pollution and mortality in a cohort of more than a million adults in Rome. *Environmental Health Perspective.* 121. (3) pp324-331.

Cisneros., Brown., Cameron., Gaab., Gonzalez., Ramandt., Veloz., Song., Schweizer. 2017. Understanding Public Views about Air Quality and Air Pollution Sources in the San Joaquin Valley, California. *Journal of Environmental and Public Health.* 4535142. pp1-7.

Chan., Van Hee., Bergen., Szpiro., DeRoo., London., Marshall., Kaufman., Sandler. 2015. Long-term air pollution exposure and blood pressure in the sister study. *Environmental Health Perspective.* 123. pp951-958.

Chang. 2006. Computational fluid dynamics simulation of concentration distributions from a point source in the urban street canyons. *Journal of Aerospace Engineering.* 19. Pp80-86.

Chatterton,TJ., Longhurst, JWS., Lesksmono,N., 2007. Ten Years of Local Air Quality Management experience in the UK: An Analysis of the process. Clean Air Environment. 41 (4), 26-31.

Challoner., Gill., 2014. Indoor/outdoor air pollution relationships in ten commercial buildings: PM2.5 and NO2. *Building and Environment.* 80.pp159-173.

Chen, C., Zhao, B.,Weschler, C.J., 2012. Indoor exposure to "outdoor PM10" assessing itsinfluence on the relationship between PM10 and short-term mortality in US cities. *Epidemiology*. 23.pp 870–878.

Chen, R., Peng, R.D., Meng, X., Zhou, Z., Chen, B. and Kan, H. 2013. Seasonal variation in the acute effect of particulate air pollution on mortality in the China Air Pollution and Health Effects Study (CAPES). *Science of The Total Environment*. 450–451.pp259-265.

Chen.,Pei., Zhou., Teng., He., Luo., Liu., 2015. Efficiency differences of roadside greenbelts with three configurations in removing coarse particles (PM10): a street scale investigation in Wuhan China. *Urban Green*.14.pp. 354-360

Chen., Samoli., Wong., Huang., Wang., Kan., 2012. Associations between short-term exposure to nitrogen dioxide and mortality in 17 Chinese cities: The China Air Pollution and Health Effects Study (CAPES). *Environmental International.* 45.pp32-38.

Chen., Burnett., Kwong., Villeneuve., Goldberg., Brook. 2013. Risk of incident diabetes in relation to long-term exposure to fine particulate matter in Ontario, Canada. *Environmental Health Perspective.* 121. pp804-810.

Chen R., Wang X., Meng X., Hua J., Zhou Z., Chen B., Kan H. 2013. Communicating air pollution-related health risks to the public: an application of the Air Quality Health Index in Shanghai, China. *Environment International.* 51. pp168-173.

Chen., Samoli., Wong., Huang., Wang., Chen.,Kan. 2012. Associations between short-term exposure to nitrogen dioxide and mortality in 17 Chinese cities: the China Air Pollution and Health Effects Study (CAPES). *Environment International*. 45.pp32–38.

Chen,H., Kwong,J., Copes,R., Tu,K., Villeneuve,P., Donkelar,A., Hystad,P., Martin,P., Murray,B., Jessiman,B., Wilton,A., Kopp,A., Burnett,R., 2017. Living near major roads and the incidence of dementia, parkinsons disease and multiple sclerosis: A population based cohort study. *The Lancet.* 339. Pp718-726.

Chen., Zhang., Huang., Song., Zhang., Qian., Trevathan., Mao., Han., Vaughn., Liu., Chen. 2016. Long-term exposure to urban air pollution and lung cancer mortality: A 12-year cohort study in Northern China. *Science of Total Environment.* 571. –855-861.

Chen., Zhou., Li., Williams., Kan., Marks., Morawska., Abramson., Yao., Qin., Wu. 2016. Air pollution and fasting blood glucose: A longitudinal study in China. *Science of the Total Environment.* 541.pp 750-755.

Chithra., Nagendra., 2012. Indoor air quality investigations in a naturally ventilated school building located close to an urban roadway in Chennai, India. *Building and Environment.* 54.pp159-167.

Chiusolo., Cadum., Stafoggia., Galassi., Berti., Faustini. 2011. Short term effects of nitrogen dioxide on mortality and susceptibility factors in ten Italian Cities: the EpiAir Study. *Environmental Health Perspectives*. 119(9)pp1233–1238.

Choi., Perera., Pac., Wang., Flak., Mroz., Jacek. 2008. Estimating individual-level exposure to airborne polycyclic aromatic hydrocarbons throughout the gestational period based on personal, indoor, and outdoor monitoring. *Environmental Health Perspectives.* 116.pp1509-1518.

Claeson, A. S., Lidén, E., Nordin, M.,Nordin, S. 2013. The role of perceived pollution and health risk perception in annoyance and health symptoms: a population-based study of odorous air pollution. *International archives of occupational and environmental health*. 86(3).pp367-374

Client Earth, 2017. Gove falls at first hurdle on air pollution, say environmental lawyers. [online]. Available from: https://www.clientearth.org/gove-falls-first-hurdle-air-pollution-plans-environmental-lawyers/ (accessed on 12th October 2017).

Client Earth, 2016. *UK agrees new air pollution law, raising awkward Brexit questions – as new coalition is launched.* [online]. Available from: https://www.clientearth.org/uk-agrees-new-air-pollution-law-raising-awkward-brexit-questions-new-coalition-launched/ (accessed on 29th June 2017).

Cole, D. C., Pengelly, L. D., Eyles, J., Stieb, D. M., Hustler, R. 1999. Consulting the community for environmental health indicator development: the case of air quality. *Health Promotion International*. 14(2) pp145-154.

Collins, J., & Koplan,J. 2009.Health impact assessment: a step toward health in all policies. *Journal of American Medical Association*. 302(3). pp315-317.

Council Directive 2003/3/EC of 28 January 2003 on *Public Access to Environmental Information.*

Coogan., White., Jerrett., Brook., Su., Seto. 2012. Air pollution and incidence of hypertension and diabetes mellitus in black women living in Los Angeles. *Circulation.* 125. Pp767-772.

Committee on the Medical Effects of Air Pollution, 2015$_a$. Nitrogen Dioxide: Health Effects of Exposure. [online]. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/411756/COMEAP_The_evidence_for_the_effects_of_nitrogen_dioxide.pdf (accessed on 15th June 2017)

Committee on the Medical Effects of Air Pollution, 2015$_b$. *Particulate Air Pollution: Health Effects of Exposure*. [online]. Available from: https://www.gov.uk/government/publications/particulate-air-pollution-health-effects-of-exposure (accessed on 15th June 2017).

Costa,L., Cole,T., Coburn,J., Chang,Y., Dao,K., Roque,P., 2017. Neurotoxicity of Traffic Related Air Pollution. *NeuroToxicology.* 59. Pp133-139.

Creswell, JW., 2014. Research Design: Qualitative, Quantitative and Mixed Method Approaches. 4th Edition. Thousand Oaks: SAGE.

Creswell, JW., 2007. Qualitative inquiry and research design: Choosing among Five Approaches. 2dn Edition. London: SAGE.

Crouse., Peters., van Donkelaar., Goldberg., Villeneuve. 2012. Risk of nonaccidental and cardiovascular mortality in relation to long-term exposure to low concentrations of fine particulate matter: a Canadian national-level cohort study. *Environmental Health Perspective.* 120. (5) pp708-714.

Coghlan., 2015. The Curious Case of NOx Pollution. *New Scientist.* 227 [3041], pp.10-11.

Davis, C (2013) *SPSS Step by Step: Essentials for social and political science*. Bristol: Policy Press.

DAERA, 2016., Air Pollution In Northern Ireland 2015. [online]. Available from: http://www.airqualityni.co.uk/assets/documents/technical-reports/AQ_NI_2015_v10.pdf

DAERA, 2017. *Air Quality Management Areas*. [online]. Available from: http://www.airqualityni.co.uk/laqm/aqma (accessed on 10th August 2017).

Daly., Zannett. 2007. Air Pollution Modelling: An Overview. *Environmental Computing Institute.* Pp15-28.

Day. 2017. Place and the experience of air quality. *Health and Place.* 13. pp249-260.

Day. 2007. Traffic-related air pollution and perceived health risk: Lay assessment of an everyday hazard. *Health, Risk and Society.* 8 (3). Pp305-322.

Dedele,A., Miskinyte,A., 2016. Seasonal variation of indoor and outdoor air quality of nitrogen dioxide in homes with gas and electric stoves. *Environmental Science and Pollution Research.* 23(17). pp 17784–17792.

Deguen., Pedrono., Segala., Mesbah. 2008. Association between pollution and public perception of air quality. A risk perception study in France. *Epidemoplogy.* 19 (6) pp216.

Demirel., Özden., Döğeroğlu., Gaga. 2012. Personal exposure of primary school children to BTEX, NO2 and ozone in Eskişehir, Turkey: Relationship with indoor/outdoor concentrations and risk assessment. *Science of the Total Environment.* 437.pp537-548.

de Kluizenaar., Kuijpers., Eekhout., Voogt., Vermeulen., Hoek., Sterkenburg., Pierik., Duyzer., Meijer., Pronk. 2017. Personal exposure to UFP in different micro-environments and time of day. *Building and Environment.* 122. Pp237-246.

deGroot, I., Loring, W., Rihm, A., Samuels, .S.W., Winkelstein, M.D.1966. People and air pollution: a study of attitudes in Buffalo, New York. *Journal of the Air Pollution Control Association.* 16. pp245-247.

Department of Transport., 2017. *Vehicle Licensing Statistic. Annual 2016 Report.* [online]. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/608374/vehicle-licensing-statistics-2016.pdf (accessed on 7th October 2017).

Department of the Environment, 1994. Public attitudes. *Digest of Environmental Protection and Water Statistics*. HMSO, London.

DEFRA, 2017. *UK plan for tackling roadside nitrogen dioxide concentrations*. [online]. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/633269/air-quality-plan-overview.pdf. Accessed on 15th August 2017.

DEFRA.,2015b. Summary of AQMA data. [online]. Available from: http://uk-air.defra.gov.uk/aqma/summary (accessed on 14th December 2016).

DEFRA., 2015. EMISSIONS OF AIR POLLUTANTS IN THE UK, 1970 TO 2014. United Kingdom.

DEFRA., 2015. Summary of Laboratory Performance in AIR/WASP NO2 Proficiency Testing Scheme (April 2013 – February 2015). [online]. Available from: http://laqm.defra.gov.uk/documents/LAQM-WASP-Rounds-121--124-and-AIR-PT-Rounds-1-3-4-6-(April-2013--February-2015)-NO2-report.pdf (accessed on 4/1/2017).

DEFRA, 2013. *Chapter 6- NO_2 concentrations and recent trends.* [online]. Available from: https://uk-air.defra.gov.uk/assets/documents/reports/aqeg/nd-chapter6.pdf (accessed on 20th April 2017).

DEFRA, 2012. *Review of air quality modelling in DEFRA.* [online]. Available from: https://uk-air.defra.gov.uk/assets/documents/reports/cat20/1106290858_DefraModellingReviewFinalReport.pdf (accessed on 10th April 2018).

DEFRA. 2010. *Evaluating the Performance of Air Quality Models.* [online]. Available from: https://ukair.defra.gov.uk/assets/documents/reports/cat05/1006241607_100608_MIP_Final_Version.pdf (accessed on 25th August 2017).

DEFRA., 2009. Local Air Quality Management Technical Guidance. [online]. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69334/pb13081-tech-guidance-laqm-tg-09-090218.pdf (accessed on 20th May 2017).

DEFRA., 2007. *Air Quality Strategy for England, Wales and Northern Ireland.* [online] Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69336/pb12654-air-quality-strategy-vol1-070712.pdf

Deguen, S., Ségala, C., Pédrono, G., & Mesbah, M. 2012. A New Air Quality Perception Scale for Global Assessment of Air Pollution Health Effects. *Risk Analysis*, 32(12). pp2043-2054.

Department for Infrastructure. 2016. Northern Ireland Transport Statistics 2015-2016. [online]. Available from: https://www.infrastructure-ni.gov.uk/system/files/publications/infrastructure/Northern-Ireland-transport-statistics-2015-16.pdf (accessed on 6th September 2017).

Department of Infrastructure. 2017. Travel Survey for Northern Ireland 2014-2016 Headline Report. [online]. Available from: https://www.infrastructure-ni.gov.uk/system/files/publications/infrastructure/TSNI-headline-report-2014-2016-press-release.pdf (accessed on 6th September 2017).

Department of Agriculture, Environment and Rural Affairs (DAERA)., 2017. *Northern Ireland Environmental Statistics Report.* [online]. Available from: https://www.daera-ni.gov.uk/sites/default/files/publications/daera/ni-environmental-statistics-report-2017_2.PDF (accessed on 12th May 2017).

Department for Transport., 2016. Vehicle Emissions Testing Programme. United Kingdom.

Dencombe,M., 2010. The Good Research Guide: For Small- Scale Social Research Projects. 4th Edition. Maidenhead. McGraw Hill Open University Press.

Denscombe, M., 2009. Ground Rules for Social Research: Guidelines for good Practice. 2nd Edition. Maidenhead: McGraw-Hill/ Open University Press.

Deng,Q., Lu,C., Ou,C., Chen,L., Yuan,H., 2016. Preconceptional, prenatal and postnatal exposure to outdoor and indoor environmental factors on allergic diseases/symptoms in preschool children. *Chemosphere.* 152. pp 459-467.

Dewulf., Neutens., Lefebvre., Seynaeve., Vanpoucke., Beckx. 2016. Dynamic assessment of exposure to air pollution using mobile phone data. *International Journal of Health Geographics*. 15 (1)pp14-20.

Dijkema., van Strien., van der Zee., Mallant., Fischer., Hoek., Brunekreef., Gehring. 2016. Spatial variation in nitrogen dioxide concentrations and cardiopulmonary hospital admissions. *Environmental Research.* 151.pp721-727.

Dijkema., Mallant., Gehring., van den Hurk., Alssema., van Strien. 2011. Long-term exposure to traffic-related air pollution and type 2 diabetes prevalence in a cross-sectional screening-study in The Netherlands. *Environmental Health.* 10.p76.

Dimitroulopoulou., Ashmore., Terry. 2013. Use of population exposure frequency distributions to simulate effects of policy interventions on NO2 exposure. *Atmospheric Environment.* 150. pp1-14

Dorizas., Assimakopoulos., Santamouris. 2015. A holistic approach for the assessment of the indoor environmental quality, student productivity, and energy consumption in primary schools. *Environmental Monitoring and Assessment.* 187. Pp4503.

Dorfman,P., Beattie, CL., Burnet, F., Gibbs,DC., Longhurst,JWS., Weitkamp, E., Leksmona, NS., 2006. A conceptual model of the role of complex science in local authority consultations about air quality management. Local Environment. 11 (4). 339-419.

Dons., Panis L., Van Poppel., Theunis., Willems., Torfs. 2011. Impact of time-activity patterns on personal exposure to black carbon. Atmospheric Environment. 45. pp3594–3602.

Dunlap,R., Jones,J., 2002. Environmental Concern: Conceptual and Measurement Issues. Handbook of Environmental Sociology. Greenwood Press, London. pp. 482–542.

Duque., Silveira., Ferrerira., Monterio. Gama., Rafael., Freitas., Borrego., Miranda. 2016. Evaluating strategies to reduce urban air pollution. *Atmospheric Environment.* 127. Pp196-204.

EC, 2008. Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. *Official Journal of the European Union.* 11th of June 2008.

Egondi., Kyobutungi., Ng., Muindi., Oti., van de Vijver, 2013. Community Perceptions of Air Pollution and Related Health Risks in Nairobi Slums. *International Journal of Environmental Research and Public Health.* 10. Pp4851-4868.

Elliott, S. J., Cole, D. C., Krueger, P., Voorberg, N., & Wakefield, S.1999. The Power of Perception: Health Risk Attributed to Air Pollution in an Urban Industrial Neighbourhood*. Risk analysis*, 19(4), pp621-634.

Environment Act 1996. London. HMSO.

Environmental Audit Committee., 2009. Air Quality. Fifth Report of Session 2009-2010. [online]. Available from: https://publications.parliament.uk/pa/cm200910/cmselect/cmenvaud/229/229i.pdf (accessed on 10th September 2014).

Environmental Audit Committee., 2014. *Action on Air Quality.* [online]. Available from: https://publications.parliament.uk/pa/cm201415/cmselect/cmenvaud/212/21202.htm (accessed on 10th March 2015).

Environmental Audit Committee, 2016. *The Future of the Natural Environment after the EU Referendum*. [online]. Available from: https://www.publications.parliament.uk/pa/cm201617/cmselect/cmenvaud/599/59902.htm (accessed on 30th June 2017).

Environmental Protection Agency Ireland.,2016. National Ambient Air Quality Monitoring Programme 2017-2022 Consultation Paper. Ireland.

Environmental Protection Agency Ireland.,2015. Air Quality in Ireland 2015. Key indicators of ambient air quality. Ireland.

Environmental Protection UK, 2017. *Air Pollution Sources.* [online]. Available from: http://www.environmental-protection.org.uk/policy-areas/air-quality/about-air-pollution/air-pollution-sources/ (accessed on 12th October 2017).

Environment (NI) Order 2002. London. HMSO.

Estarlich,M., Balester,F., Davdand,P., Llop,S., 2016. Exposure to ambient air pollution during pregnancy and pre term birth. A Spanish Multicenter cohort study. *Environmental Research.* 147.pp50-58.

Estarlich., Ballester., Davdand., Llop., Esplugues., Fernández-Somoano., Lertxundi., Guxens. 2016. Exposure to ambient air pollution during pregnancy and preterm birth: A Spanish multicenter birth cohort study. *Environmental Research.* 147. Pp50-58.

European Commission.2013. *Flash Eurobarometer 360: Attitudes of Europeans towards air quality.* Brussels.

European Comission., 2016. Transport Emissions: Air Pollutants from Road Transport. Available online: http://ec.europa.eu/environment/air/transport/road.htm. Accessed on 14th December 2016.

European Council Directive 1996/62/EC of 27th September 1996 on ambient air quality assessment and management.

European Environment Agency., 2016. *Explaining road transport emissions. A non-technical guidance.* [online]. Available from: https://www.eea.europa.eu/publications/explaining-road-transport-emissions (accessed on 18th April 2018).

European Environment Agency.2017. *Air Quality in Europe- 2017 Report.* Publications Office of the European Union. Luxembourg.

European Parliament Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe.

Eze,I., Schaffner,E., Fischer,E., Schikowski,T., Adam,M., Imboden,M., Tsai,M., Carballo,D., Von Echardstein,A., Kunxli,N., Schlinder,C., Henson,N., 2013. Long term air pollution exposure and diabetes in a population based swiss cohort. *Environmental International.* 70.pp95-105.

Eze., Schaffner., Fischer., Schikowski., Adam., Imboden. 2014. Long-term air pollution exposure and diabetes in a population-based Swiss cohort. *Environment International.* 70.pp95-105.

Eze., Hemkens., Bucher., Hoffmann., Schindler., Künzli., Schilowski., Probst-Hensch. 2015. Association between ambient air pollution and diabetes mellitus in Europe and North America: systematic review and meta-analysis. *Environmental Health Perspective.* 123. pp381–389.

Fabi, V., Andersen, RV., Corgnati ,SP. 2012. *Main physical environmental variables driving occupant behaviour with regard to natural ventilation*. In: Proceedings of the 5th International Building Physics Conference. Proceedings of the 5th International Building Physics Conference, Kyoto, Japan, p 8

Fantozzi., Monaci.,. Blanusa.,Bargagli.,2015.Spatio-temporal variations of ozone and nitrogen dioxide concentrations under urban trees and in a nearby open area. *Urban Climate.*12.pp119-127.

Faustini., Rapp., Forastiere. 2014. Nitrogen dioxide and mortality: review and meta-analysis of long-term studies. *The European Respiratory Journal.* 44 (3) pp744-753.

Favarato,G., Anderson,H., Atkinson,R., Fuller,G., Mills,L., Walton,H., 2014. Traffic related pollution and asthma prevalence in children: Quantification of associations with nitrogen dioxide. *Air Quality, Atmosphere and Health.* 7 (4) pp459-466.

Fetcht., Fischer., Fortunato., Hoek., Hoogh., Marra., Kruize., Vienneau. 2015. Associations between air pollution and socioeconomic characteristics, ethnicity and age profile of neighbourhoods in England and the Netherlands. *Environmental Pollution.* 198. Pp201-210.

Fecht., Hansel., Morley., Dajnak., Vienneau., Beevers., Toledano., Kelly., Anderson., Gulliver. 2016. Spatial and temporal associations of road traffic noise and air pollution in London: Implications for Epidemiological Studies. *Environmental International.* 88. Pp235-242.

Filleul., , Rondeau., Vandentorren., Le Moual., Cantagrel., Annesi-Maesano., Charpin. 2005. Twenty five year mortality and air pollution: results from the French PAARC survey. *Occupational and Environmental Medicine*. 62(7)pp453–460.

Fischer., Marra., Ameling., Hoek., Beelen., de Hoogh., Breugelmans., Kruize., Janssen., Houthuijs. 2015. Air Pollution and Mortality in Seven Million Adults: The Dutch Environmental Longitudinal Study (DUELS). *Environmental Health Perspectives.* 123 (7) pp697-704.

Fuks., Weinmayr., Foraster. 2014. Arterial blood pressure and long-term exposure to traffic-related air pollution: an analysis in the European Study of Cohorts for Air Pollution Effects (ESCAPE). *Environmental Health Perspective.* 122. Pp896-905.

Fu., Liu., Weiss., Zhang., Huang., Tao., 2017. Effects of canyon geometry on the distribution of traffic-related air pollution in a large urban area: Implications of a multi-canyon air pollution dispersion model. *Atmospheric Environment.* 165. Pp111-121.

Fung, C. C., Yang, P., and Zhu, Y. F. 2014. Infiltration of Diesel Exhaust into a Mechanically Ventilated Building. Indoor Air. Hong Kong.

Gallagher., Gill., McNabola. 2013. The passive control of air pollution exposure in Dublin, Ireland: A combined measurement and modelling case study. *Science of the Total Environment.* 458-460. Pp331-343.

Gallagher., Baldauf., Fuller., Kumar., Gill., McNabola., 2015. Passive methods for improving air quality in the built environment: A review of porous and solid barriers. *Atmospheric Environment.*120.pp61-70.

Gasana,J., Dillikar,D., Mendy,A., Forno,E., Vieira,R., 2012. Motor vehicle air pollution and asthma in children. *Environmental International.*117.pp36-45.

Gatto., Henderson., Hodis., John., Lurmann., Chen., Mack. 2014. Components of air pollution and cognitive function in middle-aged and older adults in Los Angeles. *NeuroToxicology.* 40. Pp1-7.

Gehring,U., Wija,A., Fischer,P., Jongsite,J., Kerkhaf,M., 2011. Traffic Related Air Pollution, Pre term birth and term birth weight in PIAMA birth cohort study. *Environmental Research.*111.pp125-135.

Gehring.,Dijkema., van der Wal., Fischer., Brunekreef. 2011_b. Traffic-related air pollution and pregnancy outcomes in the Dutch ABCD birth cohort study. *Occupational Health Medicine.* 68.pp36-43.

Gehring., Wijga., Hoek., Bellander., Berdel., Bruske., 2015. Exposure to air pollution and development of asthma and rhinoconjunctivitis throughout childhood and adolescence: a population-based birth cohort study. *Lancet Respiratory Medicine.* 3(12).pp933-942.

German Partnership for Sustainable Mobility., 2015. *Clean Air-Made in Germany.* Germany.

Ghafghazi, G. and Hatzopoulou, M.2015. Simulating the air quality impacts of traffic calming schemes in a dense urban neighborhood. Transportation Research Part D: *Transport and Environment*. 35.pp11-22.

Ghosh., Joad., Benes., Dostal., Sram. 2012. Ambient nitrogen oxides exposure and early childhood respiratory illnesses. *Environmental International.* 39 (1). Pp96-101.

Gilbert. 2003. Ambient nitrogen dioxide and distance from a major highway. *Science of the Total Environment*, 312(1–3):43–46.

Gillespie- Bennett., Pierse., Wickens., Crane., Howden-Chapman. 2011. Housing heating and health study research team. The respiratory health effects of nitrogen dioxide in children with asthma. *European Respiratory Journal.* 38.pp303-309.

Goldberg., Burnett., Stieb., Brophy., Daskalopoulou., Valois., Brook. 2013. Associations between ambient air pollution and daily mortality among elderly persons in Montreal, Quebec. *Science of the Total Environment.* 463-464. Pp931-942.

González Ortiz A. 2013. *Air implementation pilot project (2012-2013). Lessons learnt from the implementation of air quality legislation at urban level. Report No. 7.* European Environment Agency. Denmark, 70 pp [online] http://www.eea.europa.eu/publications/air-implementation-pilot-2013/download (accessed on 2nd August 2017).

Gray,D., 2014. Doing Research in the Real World. 3rd Edition. Los Angeles: SAGE.

Greenhalgh., Taylor., 2007. How to read a paper: Papers that go beyond numbers (qualitative research). BMJ. 315: 740-743.

Greater London Authority., 2017. *Mayor more than doubles funding to clean up Londons Air.* [online]. Available from: https://www.london.gov.uk/press-releases/mayoral/mayor-doubles-funding-to-clean-up-londons-air (accessed on 6th August 2017).

Gromke., Jamarkattel.,Ruck.,2016. Influence of roadside hedgerows on air quality in urban street canyons. *Atmospheric Environment.*139.pp75-86.

Gromke, C. and Blocken, B. 2015. Influence of avenue-trees on air quality at the urban neighborhood scale. Part II: Traffic pollutant concentrations at pedestrian level. *Environmental Pollution*. 196. 176-184.

Gromke., Ruck. 2012. Pollutant concentrations in street canyons of different directions. *Boundary-Layer Meteorol*.144.pp41-64.

Grundström., Pleijel.,2014. Limited effect of urban tree vegetation on NO2 and O3 concentrations near a traffic route. *Environmental Pollution.* 189.pp73-76.

Gu, J., Kraus, U., Schneider, A., Hampel, R., Pitz, M., Breitner, S., Wolf, K., Hänninen, O.,Peters, A., Cyrys, J., 2015. Personal day-time exposure to ultrafine particles in different micro-environments. *International Journal of Hygiene and Environmental Health*. 218.pp 188–195.

Guarnieri,M., Balmes,J., 2010. Outdoor Air Pollution and Asthma. *The Lancet.* 383 (9928) pp 1581-1592.

Gulia., Nagendra., Khare., Khanna. 2015. Urban Air Quality Management- A Review. *Atmospheric Pollution Research.* 6 (2). Pp286-304.

Habermann., Billger., Eugensson., 2015. Land use regression as a method to model air pollution. *Procedia Engineering.* 115. Pp21-28.

Haddad., Elliott., Pengelly. 2012. Health Impacts of Air Pollution: A Life Course Approach for Examining Predictors of Respiratory Health in Adulthood. *Annals of Epidemiology.* 22 (4) pp239-249.

Hagler.,Tang., Freeman., Heist., Perry., Vette. 2011. Model evaluation of roadside barrier impact on near-road air pollution. *Atmospheric Environment.*45.pp2522-2530.

Hajat., Hsia., O'Neill. 2015. Socioeconomic disparities and air pollution exposure: a global review. *Current Environmental Health Reports.* 2. (4). Pp440-450.

Halady, 2010. Does awareness to climate change lead to behavioural change? *International Journal of Climate Change Strategies and Management.* 2 (1) pp 6-22.

Harrison,R.,2017. *Air Quality at risk: Brexit and lobbying from member states could stall progress on reducing air pollution.* [online]. Available from: http://blogs.lse.ac.uk/europpblog/2017/02/22/air-quality-at-risk-brexit/ (accessed on 29th June 2017).

Hayes., Parkhurst., Longhurst. 2009. Managing Local Traffic Related Air Pollution in England. *Polis Conference.* Brussels, Belgium.

Han., Guo., Li., Sang., 2013. Nitrogen dioxide inhalation induces genotoxicity in rats. *Chemosphere*. 90 (11). Pp2737-2782.

Hannam., McNamee., Baker., Sibley., Agius. 2013. Maternal residential proximity to major roads in North West England and adverse pregnancy outcomes. *Journal of Occupational and Environmental Medicine.* 55 (11). Pp1329-1336.

Hanlonen., Blangiardo., Toledano., Fecht., Gulliver., Anderson., Beevers., Dajnak., Kelly., Tonne. 2016. Long-term exposure to traffic pollution and hospital admissions in London. *Environmental Pollution.* 208. Pp48-57.

Health Effects Institute., 2016. Advanced Collaborative Emissions Study (ACES): Lifetime Cancer and Non-Cancer Assessment in Rats Exposed to New-Technology

Diesel Exhaust. [online]. Available from: https://www.healtheffects.org/publication/advanced-collaborative-emissions-study-aces-lifetime-cancer-and-non-cancer-assessment (accessed on 20th June 2017).

Health Effects Institute.,2010. Traffic Related Air Pollution: A critical Review of the Literature on Emissions, Exposure and Health Effects. [online]. Available from: https://www.healtheffects.org/system/files/SR17TrafficReview_Exec_Summary.pdf (accessed on 16th June 2017).

Health Effects Institute, 2015., *Analysis of Personal and Home Characteristics Associated with the Elemental Composition of PM2.5 in Indoor, Outdoor, and Personal Air in the RIOPA Study.* Boston. Health Effects Institute.

Heinrich., Thiering., Rzehak., Kramer.,Hochadel., Gehring. 2013. Long-term exposure to NO2 and PM10 and all-cause and cause-specific mortality in a prospective cohort of women. *Occupational and Environmental Medicine*, 70(3).pp179–186.

Hitchcock,C., Colan,B., Kay,D., 2014. *Air Quality and Road Transport. Impacts and Solutions.* RAC Foundation. London.

Hjortebjerg,D., Anderson,A., Ketzel,M., Pederson,M., Nielsen,O., Sorsensen., 2016. Associations between maternal exposure to air pollution and traffic noise and newborns size at birth. A cohort study. *Environmental International.* 95.pp1-7.

HM Government:1956. Clean Air Act 1956. [online] Available From: http://www.opsi.gov.uk/acts/acts1956a (accessed 1st December 2016).

HM Government, 2002. The Environment (NI Order) 2002. [online] Available from: http://origin-www.legislation.gov.uk/nisi/2002/3153/pdfs/uksi_20023153_en.pdf (accessed 10th December 2016).

HM Government, 2010. The Air Quality Standards Regulations (Northern Ireland) 2010. [online] Available from: http://www.legislation.gov.uk/nisr/2010/188/contents/made (accessed on 1st December 2010).

Hoek., Krishnan., Beelen., Peters., Ostro., Brunekreef,., Kaufman. 2013. Long-term air pollution exposure and cardio- respiratory mortality: a review. *Environmental Health.* 28 (1) pp43.

Hofman.,Samson., 2014. Biomagnetic monitoring as a validation tool for local air quality models: a case study for an urban street canyon. *Environmental International.*70.pp50-61.

Hofman., Bartholomeus., Janssen., Calders., Wuyts., Van Wittenberghe., Samson., 2016. Influence of tree crown characteristics on the local PM10 distribution inside an urban street canyon in Antwerp (Belgium): a model and experimental approach. *Urban Green.* 20.pp265-276.

Howel, D., Moffatt, S., Bush, J., Dunn, C. E. and Prince, H., 2003. Public views on the links between air pollution and health in Northeast England. *Environmental Research*. 91, 163 – 171.

Hsu., Hwang., Kinney., Lin. 2017. Seasonal and temperature modifications of the association between fine particulate air pollution and cardiovascular hospitalization in New York state. S*cience of the Total Environment.* 578. Pp626-632.

Huang., Roa., Jan van der Kuijp., Bi., Liu., 2017. A comparison of individual exposure, perception, and acceptable levels of PM2.5 with air pollution policy objectives in China. *Environmental Research.* 157. pp78-86.

In House Policy Consultants (IHPC), 2010. Review of Local Air Quality Management: Report to DEFRA and Devolved Administrations. DEFRA. London.

International Council for Clean Transportation. 2017. *CO2 emissions from new passenger cars in the EU: Car manufacturers' performance in 2016.* [online]. Available from: http://www.theicct.org/sites/default/files/publications/PV-EU-OEM_ICCT-Briefing_03072017_vF.pdf (accessed on 16th August 2017).

ICCT, 2014. *Real-world exhaust emissions from modern diesel cars*. [online]. Available from: http://www.theicct.org/real-world-exhaust-emissions-modern-diesel-cars (accessed on 19th May 2015).

International Council on Clean Transportation., 2014. Real world exhaust emissions from modern diesel cars: A Meta -Analysis of PEMS emissions data from euro 6 Diesel Passenger cars. [online]. Available from: http://www.theicct.org/sites/default/files/publications/ICCT_PEMS-study_diesel-cars_20141010.pdf (accessed on 10th October 2015).

Information Commissioners Office, 2017. *What are the Environmental Information Regulations?* [online]. Available from: https://ico.org.uk/for-organisations/guide-to-the-environmental-information-regulations/what-are-the-eir/ (accessed on 25th August, 2017).

Jones,M., Longhurst,JWS., 2010. Managing Air Quality at the Local Level: A Case Study. International Journal on Sustainable Development Planning. 5 (3). 223-237.

Janhäll, S. 2015. Review on urban vegetation and particle air pollution – Deposition and dispersion. *Atmospheric Environment*. 105.pp130-137.

Jayasooriya., Muthukumaran., Perera., 2016. Green infrastructure practices for improvement of urban air quality. *Urban Green.* 21.pp34-47.

Jerrett M, McConnell R, Chang CC, Wolch J, Reynolds K, Lurmann F, Gilliland F, Berhane K. 2010. Automobile traffic around the home and attained body mass index: a longitudinal cohort study of children aged 10–18 years. *Preventative Medicine*. 50.pp50-58.

Jerrett., Burnett., Beckerman., Turner., Krewski., Thurston., Martin., van Donkelaar., Hughes., Shi., Gapstur., Thun. 2013. Spatial analysis of air pollution and mortality in California. *American Journal of Respiratory Health and Critical Care Medicine.* 188(5) pp593-599.

Jin., Guo., Wheeler., Kan.,Che. 2014. Evaluation of impacts of trees on PM2.5 dispersion in urban streets. *Atmospheric Environment.* 99.pp227-287.

Johnson., Williams., Fan., Lin., Hudgens., Gallagher., Vette., Neas. 2010. Participant-based monitoring of indoor and outdoor nitrogen dioxide, volatile organic compounds, and polycyclic aromatic hydrocarbons among MICA-Air households. *Atmospheric Environment.* 44 (38). Pp4927-4936.

Johnson B.2012. Experience with urban air pollution in Paterson, New Jersey and implications for air pollution communication. *Risk Analysis*. 32. pp39-53.

Jovanovic., Vučićević., Turanjanin., Živković., Spasojević. 2014. Investigation of indoor and outdoor air quality of the classrooms at a school in Serbia. *Energy.* 77 (1). pp42-48.

Karra., Epshtein., Neophytou. 2017. Air flow and pollution in a real, heterogeneous urban street canyon: A field and laboratory study. *Atmospheric Environment.* Corrected Proof.

Karottkia., Beköb., Clausenb., Madsenc., Andersena., Masslingd., Ketzeld.,2014. Cardiovascular and lung function in relation to outdoor and indoor exposure to fine and ultrafine particulate matter in middle-aged subjects. *Environmental International.* 73.pp372-381.

Karakatsani., Kapitsimadis., Pipikou., Chalbot., Kavouras., Orphanidou., Papiris., Katsouyanni. 2010. Ambient air pollution and respiratory health effects in mail carriers. *Environmental Research.* 110 (3) pp 278-285.

Kaplan, G., Everson, S., Lynch, J .2000. Promoting health: intervention strategies from social and behavioral research. Washington, DC: National Academy Press, 2000:37–80.

Katsoulis., Dimakopoulou., Pedeli., Trichopoulos., Gryparis., Trichopoulou. 2014. Long-term exposure to traffic-related air pollution and cardiovascular health in a Greek cohort study. *Science of the Total Environment.* 490. pp934-940.

Kaufman,J., Brunekreef,B., Hoffmann,B., 2016. Air Pollution and Heart Disease. *The Lancet.* 388.pp640-641.

Kaufman,J., Adar,S., Barr,G., Budoff,M., Burke,G., Curl,C., Davilgus,M., 2016. Association between air pollution and coronary artery calcification within six metropolitan areas in the USA. A Longitudinal Cohort Study. 388.pp696-704.

Khreis,H., Kelly,C., Tate,J., Parslow,R., Lucas,K., Nieuweenhuijsen,M., 2017. Exposure to traffic related air pollution and risk of development of childhood asthma: A systematic review and meta analysis. *Environmental International.* 100. Pp1-31.

King, E.A., Murphy, E., McNabola, A., 2009. Reducing pedestrian exposure to environmental pollutants: a combined noise exposure and air quality analysis approach. *Transport Research.*14. pp309-316.

Kim., Jahan., Kabir. 2013. A review on human health perspective of air pollution with respect to allergies and asthma. *Environmental Information.* 59.pp41-52.

Kim, M., Yi, O., Kim, H. 2012.The role of differences in individual and community attributes in perceived air quality. *Science of the Total Environment.* 425. pp20-26.

Kim., Lee., Kwon., Jung., Lee., Song., Yang., Seo., Kwon., Hong. 2014. Traffic-related air pollution is associated with airway hyperresponsiveness. *Journal of Allergy and Clinical Immunology.* 133 (6) pp1763-1765.

Kirkby, A.V., 1972. Perception of air pollution as a hazard and individual adjustment to it in Exeter, Shefeld and Edinburgh. Paper: Man and Environment Commission Symposium, Calgary, July 24-30

Kotzias., Geiss., Tirendi., Barrero., Reina.,2011. Exposure to multiple air contaminants in public buildings, schools and kindergartens – the European indoor air monitoring and exposure assessment (AIRMEX) study. *Environmental Bulletin.*18.pp670-681.

Kornartit,C.,Sokhi,R., Burton,M., Ravindra. 2010. Activity pattern and personal exposure to nitrogen dioxide in indoor and outdoor microenvironments. *Environment International.* 36. Pp36-45.

Kramer., Herder., Sugiri., Strassburger., Schikowski., Ranft. 2010. Traffic-related air pollution and incident type 2 diabetes: results from the SALIA cohort study. *Environmental Health Perspective.* 118. pp1273-1279.

Kuklinska,K., Wolska,L., Namiesnik,J., 2015. Air Quality Policy in the U.S. and the EU. Atmospheric Pollution. 6. 129-137.

Kumar, R., 2014. Research Methodology: a step by step guide for beginners. 4th Edition. Los Angeles. SAGE.

Kumar., Morawska., Martani., Biskos., Neuphytou., Sabatino., Bell., Norford., Britter. 2015. The use of low cost sensing for managing air pollution in cities. *Environmental International.* 75.pp119-205.

Lai, H.K.; Bayer-Oglesby, L.; Colvile, R.; Gotschi, T.; Jantunen, M.J.; Kunzli, N.; 27 Kulinskaya, E.; Schweizer, C.; Nieuwenhuijsen, M.J. 2006. Determinants of indoor air 28 concentrations of PM2.5, black smoke and NO2 in six European cities (EXPOLIS study). *Atmospheric Environment*. 40.pp1299-1313.

Lagravinese., Moscone., Tosetti., Lee. 2014. The impact of air pollution on hospital admissions: Evidence from Italy. *Regional Science and Urban Economics.* 59. Pp278-285.

Largeron and Staquet. 2016. Persistent inversion dynamics and wintertime PM10 air pollution in Alpine valleys. *Atmospheric Environment.* 135. Pp92-108.

Laurent., Hu., Li., Kleeman., Bartell., Cockburn., Escobedo., Wu. 2016. Low birth weight and air pollution in California: Which sources and components drive the risk? *Environmental International.* 92-93. Pp471-477.

Lee., Roberts., Catov., Talbott., Ritz. 2013. First Trimester Exposure to Ambient Air Pollution, Pregnancy Complications and Adverse Birth Outcomes in Allegheny County, PA. *Maternal Child Health Journal.* 17 (3). Pp545-555.

Lee,P., Liu.L., Sun,Y., Chen,Y., Chi,L., Li,C., Yu,H., Ritz,B., 2016. Traffic related air pollution and increased risk of Parkinson's Disease in Taiwan. A nationwide study. 96.pp75-81.

Lercher, P., Schmitzberger, R., & Kofler, W. 1995. Perceived traffic air pollution, associated behaviour and health in an alpine area. *Science of the total environment*, 169(1). pp71-74.

Lewis,A., Edwards,P. 2016. Personal Air Pollution Sensors. *Nature Journal of Science.* 535(7610) pp29-31.

Leung.,2001. How to design a questionnaire. Student BMJ. 9. 187-189.

Llop., Ballester., Estarlich., Esplugues., Rebagliato., Iniguez. 2010. Preterm birth and exposure to air pollutants during pregnancy. *Environmental Research.* 110.pp173-176.

Lin., Meng., Chen., Huang., Ma., Chen., Gui., Chu., Kan. 2017. Ambient air pollution, temperature and kawasaki disease in Shanghai, China. *Chemosphere.* 186. Pp817-822.

Li., Yan., Xu., Huand., Wang., Xie. 2017. Characteristics and source distribution of air pollution in winter in Qingdao, eastern China. *Environmental Pollution.* 224. Pp44-53.

Li, L., Qian, J., Ou, C., Zhou, Y., Guo, C. and Guo, Y. 2014. Spatial and temporal analysis of Air Pollution Index and its timescale-dependent relationship with meteorological factors in Guangzhou, China, 2001–2011. *Environmental Pollution*. 190.pp75-81.

Li., Lu., Di He., Peng., Gao., Wang. 2015. The impacts of roadside vegetation barriers on the dispersion of gaseous traffic pollution in urban street canyons. *Urban Green.* 17.pp80-91.

Liu,X.,Mu,R., 2016. Public Environmental Concern in China: Determinants and Variations. *Global Environmental Concern.* 37. Pp.116-127.

Liu., Tsai., Keidel., Gemperli., Ineichen., Rochat., Kunzli. 2012. Long Term Exposure Models for traffic related NO2 across geographically diverse areas over separate years. *Atmospheric Environment.* 46. Pp460-471.

Liu., Ming-Ma., Liu., Han., Chuang. 2015. Effects of commuting mode on air pollution exposure and cardiovascular health among young adults in Taipei, Taiwan. *International Journal of Hygiene and Environmental Health.* 218 (3) pp319-323.

Longhurst,JWS., Irwin,J., Chatterton,T., Hayes, E., Leksmono, N., Symons,J., 2009. The development of effects based air quality management regimes. Atmospheric Environment, 43. 64-78.

Longhurst, J., Barnes, J., Chatterton, T., Hayes, E. T., Irwin, J. G. and Olowoporoku, A. 2010. Recalibrating the United Kingdom's local air quality management regime to deliver desired goals. *Air Pollution XVIII.* Southampton & Boston: WIT Press, pp. 73-82.

Longhurst, J. 2016. *60 years of Health Protection under the Clean Air Acts. In: Marking 60 Years of the Clean Air Acts*. Millbank, London. UK.

London Air. 2017. *About London Air*. [online]. Available from: https://www.londonair.org.uk/LondonAir/General/about.aspx (accessed on 25th August 2017).

Lui., Tsai., Keidel., Gemperli., 2012. Long-term exposure models for traffic related NO2 across geographically diverse areas over separate years. *Atmospheric Environment.* 46. Pp460-471.

Maheswaran., Pearson., Smeeton., Beevers., Campbell., Wolfe. 2010. Impact of outdoor air pollution on survival after stroke: population-based cohort study. *Stroke.* 41.pp869-877.

McAdam., Steer., Perrotta. 2011. Using continuous sampling to examine the distribution of traffic related air pollution in proximity to a major road. *Atmospheric Environment.* 45 (12) pp2980-2086.

McBoyle, G.R., 1972. The public perception of air pollution in Aberdeen. *Man and Environment Commission Symposium*. Calgary.

McNabola, A., Broderick, B.M., Gill, L.W., 2008. Reduced exposure to air pollution on the boardwalk in Dublin, Ireland. Measurement and prediction. *Environmental International*. 34.pp86-93.

Mcnabola., Broderick., Gill. 2009. A numerical investigation of the impact of low boundary walls on pedestrian exposure to air pollutants in urban street canyons. *Science of the Total Environment.* 407. Pp760-769.

Mead., Popoola., Stewart., Landshoff., Callega., Hayes., Baldovi., McLeod., Hodgson., Dicks., Lewis., Cohen., Baron., Saffell., Jones. 2013. The use of electrochemical sensors for monitoring urban air quality in low cost high density networks. *Atmospheric Environment.* 70. Pp186-203.

Meadow, J. F., Altrichter, A. E., Kembel1, S. W., Kline, J., Mhuireach, G., Moriyama, M., et al. 2014. Indoor airborne bacterial communities are influenced by ventilation, occupancy, and outdoor air source. *Indoor Air*.24.pp 41–48.

Meadows., 2003. Questionnaire Design. British Journal of Community Nursing. 8.12. 562-570.

Meier., Schindler., Eeftens., Aguilera., Ducret-Stich., Ineichen., Davey., Phuleria., Hensch., Tsai., Künzli. 2015. Modeling indoor air pollution of outdoor origin in homes of SAPALDIA subjects in Switzerland. *Environment International.* 82. pp85-91.

Mendola., Wallace., Hwang., Liu., Robledo., Männistö., Sundaram., Sherman. 2016. Preterm birth and air pollution: Critical windows of exposure for women with asthma. *Journal of Allergy and Clinical Immunology*. 138(2). Pp432-440.

Michie., Van Stralen., West., 2011. The Behaviour Change Wheel: A new method for characterising and designing behaviour change interventions. *Implementation Science.*

Milner., Hamilton., Das., Davies., Wilkinson., 2015. What should the ventilation objectives be for retrofit energy efficiency interventions of dwellings? *Building Services Engineering Research and Technology.* 36 (2).pp221-229.

Minguillón., Schembari., Triguero-Mas., Nazelle., Dadvand., Figueras., Salvado., Grimalt., Nieuwenhuijsen. 2012. Source apportionment of indoor, outdoor and personal PM2.5 exposure of pregnant women in Barcelona, Spain. *Atmospheric Environment.* 59.pp426-436.

Ministry of Environment., 2016. National Clean Air Programme (NCAP) – India. [online]. Available from: http://www.indiaenvironmentportal.org.in/content/452706/national-clean-air-programme-ncap-india-concept-note/ (accessed on 14th April 2017).

Mohammadyan., Ashmore., Shabankhani., 2010. Indoor PM2.5 concentrations in the office, café, and home. *International Journal of Occupational Hygiene.* 2.pp57-62.

Moorcroft,S and Dore,C., 2013. Review of the Effectiveness of Local Authority Action Plans and Future Policy Options for LAQM. Report number 1372/1/F1. DEFRA.

Moffatt, S., Bush, J., Dunn, C., Howel, D.,Prince, H.,1999. *Public awareness of air quality and respiratory health and the impact of health advice.* Department of Epidemiology and Public Health, University of Newcastle upon Tyne, and Department of Geography, University of Durham.

Namdeo., Tiwary., Farrow. 2011. Estimation of age-related vulnerability to air pollution: Assessment of respiratory health at local scale. *Environmental International.* 37 (5) pp829-837.

National Grid., 2017. *Our Energy Insights. Forecourt thoughts on mass charging of electric vehicles.* [online]. Available from: http://fes.nationalgrid.com/media/1221/forecourt-thoughts-v10.pdf (accessed on 25th August 2017).

National Research Council. 2007. *Models in environmental regulatory decision making*. The National Academies Press. Washington DC, USA.

New Scientist. 2017. France plans to ban all new petrol and diesel cars by 2040. [online]. Available from: https://www.newscientist.com/article/2139995-france-

plans-to-ban-all-new-petrol-and-diesel-cars-by-2040/ (accessed on 16th August 2017).

New Scientist, 2016., Brexit Science. *New Scientist.* 230 (3070). Pp6.

NHS., 2016. *Causes of High Blood Pressure (Hypertension).* [online]. Available from: http://www.nhs.uk/Conditions/Blood-pressure-(high)/Pages/Causes.aspx (accessed on 14th August 2017).

Ning.,Hudda.,Daher., Kam.,Herner., Kozawa., Mara., Sioutas. 2010. Impact of roadside noise barriers on particle size distributions and pollutants concentrations near freeways. *Atmospheric Environment.* 44.pp3118-3127.

Nielsen,O., Anderson,Z., Beelan,R., Samoli,E., Stafoggia,M., 2013. Air Pollution and lung cancer incidence in 17 European Cohorts: Perspective analyses for ESCAPE. *The Lancet.* 14.pp813-822.

Nikolopoulou., Kleissl., Linden., Lykoudis. 2011. Pedestrians' perception of environmental stimuli through field surveys: focus on particulate pollution. *Science of the Total Environment.* 409. pp2493-2502.

Norwegian EV. 2017. *Norwegian EV Policy*. [online]. Available from: http://elbil.no/english/norwegian-ev-policy/ (accessed on 16th August 2017).

Nowak, D.J., Hirabayashi, S., Bodine, A. and Hoehn, R. 2013. Modelled PM2.5 removal by trees in ten U.S. cities and associated health effects. *Environmental Pollution*. 178. pp395-402.

Northern Ireland Executive, 2016. Programme for Government Consultation Document. [online]. Available from: https://www.northernireland.gov.uk/sites/default/files/consultations/newnigov/pfg-consulation-document.PDF (accessed on 20 March 2017).

Noonan, D.2011. Smoggy with a Chance of Altruism: Using Air Quality Forecasts to Drive Behavioural Change*. American Enterprise Institute*. 8.pp14.

Northern Ireland Environment Link., 2012. Effecting Behaviour Change Through Environmental Messaging. [online]. Available from: http://www.nienvironmentlink.org/cmsfiles/files/Publications/Behaviour-Change--Env-Msging.pdf (accessed on 3rd August 2017).

Obara., Roberts., Young., Williams. 2011. Influence of vehicular traffic on a major trunk road on rural air quality in UK. *Microchemical Journal.* 99 (2) pp 344-351.

Olowoporoku,A., Hayes,E., Leksmono,N., Longhurst, JWS., Parkhurst,G., 2010. A longitudinal study of the links between Local Air Quality Management and Local Transport Planning Policy Processes in England. Journal of Environmental Planning and Management. 53 (3).385-403.

Olowoporoku, A., Hayes, E. T., Longhurst, J. and Parkhurst, G.2012. The rhetoric and realities of integrating air quality into local transport planning process. *Journal of Environmental Management.* 101 (30) pp 23-32.

Oltra,C., Sala,R. Research on Public Perception and Engagement Practices in Urban Air Pollution. [online]. Available from: http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/45/046/45046419.pdf (accessed on 24th May 2016).

Oltra,C., Sala, R., 2015. Communicating the risks of urban air pollution to the public. A study of urban air pollution sources. *The International Journal of Environmental Pollution.* 31 (4) pp261-375.

Ouidir., Allemand., Caen., Morelli., Cracowski., Pontet., Pin. 2015. Estimation of exposure to atmospheric pollutants during pregnancy integrating space–time activity and indoor air levels: Does it make a difference? *Environmental International.* 84. Pp161-173.

Ozkaynak.,Baxter., Burke. 2013. Evaluation and application of alternative air pollution exposure metrics in air pollution epidemiology studies. *Journal of Exposure Science and Environmental Epidemiology.* 23. Pp565.

Padula., Mortimer., Hubbard., Lurmann., Jerrett., Tager. 2012. Exposure to Traffic-related Air Pollution During Pregnancy and Term Low Birth Weight: Estimation of Causal Associations in a Semiparametric Model. *American Journal of Epidemiology.* 176 (9) pp815-824.

Papanastasiou, D.K., Melas, D. and Kambezidis, H.D.2015 Air quality and thermal comfort levels under extreme hot weather. *Atmospheric Research*.152.pp 4-13.

Parkes, 2016., Brexit: A storm in a teacup? *Renewable Energy Focus.* 17 (5). Pp188-190.

Patton., Perkins., Zamore., Levy., Brugge., Durant., 2014. Spatial and temporal differences in traffic-related air pollution in three urban neighborhoods near an interstate highway. *Atmospheric Environment.* 99.pp309-321.

Pantavou., Lykoudis., Psiloglou.2017. Air quality perception of pedestrians in an urban outdoor Mediterranean environment: A field survey approach. *Science of the Total Environment.* 574. pp663-670.

Perth Air Quality Co-Ordinating Committee. 2016. *Perth Air Quality Co-ordinating Committee Report Card 2015-2016.* [online]. Available from: https://www.der.wa.gov.au/images/documents/about/committees/AQ-reportcard15-16.pdf (accessed on 26th August 2016).

Pinault., Crouse., Jerrett., Brauer., Tjepkema. 2016. Spatial associations between socioeconomic groups and NO2 air pollution exposure within three large Canadian cities. *Environmental Research.* 147. Pp373-382.

Plaia A. and Ruggieri M. (2011). Air quality indices: a review. *Reviews in Environmental Science and Biotechnology.* 10.pp165-179.

Qin., Xiao., Zhu., Li., Yang., Gu., Xia., Su., Liu., Woodward. 2017 The interactive effects between high temperature and air pollution on mortality: A time-series analysis in Hefei, China. *Science of the Total Environment.* 575. Pp1530-1537.

Ramsey, N.R., Klein, P.M. and Moore B. 2014. The impact of meteorological parameters on urban air quality. *Atmospheric Environment*. 86. pp58-67.

Rankin, R. E. 1969. Air pollution control and public apathy. *Journal of the Air Pollution Control Association*. 19(8). pp565-569.

Rajagopalan., Brook. 2012. Air pollution and type 2 diabetes: mechanistic insights. *Diabetes.* 61. pp3037-3045.

Rakowska., Wong., Townsend., Chan., Drinovec., Ning., 2014. Impact of traffic volume and composition on the air quality and pedestrian exposure in urban street canyon. *Atmospheric Environment.* 98.pp260-270.

Regettli., Phuleria., Tsai., Schlindler.,Nazelle., Stich., Perez., Hensch. 2015. The relevance of commuter and work/school exposure in an epidemiological study on traffic-related air pollution. *Journal of Exposure Science and Environmental Epidemiology.* 25(5).pp474-481.

Requia., Adams., Arain., Koutrakis., Lee., Ferguson. 2017. Spatio-temporal analysis of particulate matter intake fractions for vehicular emissions: Hourly variation by micro-environments in the Greater Toronto and Hamilton Area, Canada. *Science of the Total Environment.* 599-600. Pp1813-1822.

Ritz,B., Lee,P., Hansen,J., LAssen,C., Ketzel,M., Sorensen,M., Nielsen,R., 2016. Traffic related air pollution and Parkinson disease in Denmark. A case control study. *Environmental Health Perspective.* 124.(3)pp351-356.

Rivas., Kumar., Zanker., 2017. Exposure to air pollutants during commuting in London: Are there inequalities among different socio-economic groups? *Environment International.*101.pp143-157.

Rivas., Viana., Moreno., Pandolfi., Amato., Reche., 2014. Child exposure to indoor and outdoor air pollutants in schools in Barcelona, Spain. *Environmental International.* 69.pp200-212.

Robson,C., McCarton, K., 2016. Real World Research: A Resource for users of social research methods in applied settings. 4th Edition. Chichester: Wiley.

Rodríguez., Dupont-Courtade., Oueslati., 2016. Air pollution and urban structure linkages: Evidence From European cities. *Renewable and Sustainable Energy Reviews.* 53. pp1-9.

Royal College of Physicians (RCP), 2016. Every breath we take: the lifelong impact of air pollution. [online]. Available from: https://www.rcplondon.ac.uk/projects/outputs/every-breath-we-take-lifelong-impact-air-pollution (accessed on 15th June 2017).

Roswell., Raaschou-Nielsen., Ketzel., Gammelmark., Overvad., Olsen., 2017. Long-term residential road traffic noise and NO2 exposure in relation to risk of incident myocardial infarction – A Danish cohort study. Environmental Research. 156.pp80-86.

Roosbroeck., Wichmann., Janssen., Hoek., van Wijnen., Lebret., Brunekreef., 2006., Long-term personal exposure to traffic-related air pollution among school children, a validation study. *Science of the Total Environment.* 368.pp565-573.

Rugg,G., Petre, M., 2007. A gentle Guide to Research Methods. Maidenhead: Open University Press

Russo, A., Trigo, R.M., Martins, H. and Mendes, M.T.2014. NO2, PM10 and O3 urban concentrations and its association with circulation weather types in Portugal. *Atmospheric Environment*. 89.pp768-785.

Sajani., Trentini., Rovelli., Ricciardelli., Marchesi., Maccone., Bacco., Ferrari., 2016. Is particulate air pollution at the front door a good proxy of residential exposure? *Environmental Pollution.* 213. pp347-358.

Saksena,S. 2011. Public perceptions of urban air pollution risks. *Risk, Hazards and Crisis in Public Policy*.2. pp1-19.

Sarnat SE, Klein M, Sarnat JA, Flanders WD, Waller LA, Mulholland JA, Russell AG, Tolbert PE., 2010. An examination of exposure measurement error from air pollutant spatial variability in time-series studies. Journal of Exposure Science and Environmental Epidemiology.20.pp135-146.

Santina, O., Itarda,L. 2010. Occupants' behaviour: determinants and effects on residential heating consumption. *Build Research and Information*. 38.pp318–338.

Sayegh., Tate., Ropkins., 2016. Understanding how roadside concentrations of NOx are influenced by the background levels, traffic density, and meteorological conditions using Boosted Regression Trees. *Atmospheric Environment.* 127.pp163-175.

Schembarri., Triguero-Mas., Nazelle., Dadvand., Vrijheid., Cirach., Martinez., Figueras., Querol., Basagaña., 2013. Personal, indoor and outdoor air pollution levels among pregnant women. *Atmospheric Environment.* 64. Pp287-295.

Scottish Government., 2015. Cleaner Air For Scotland: The Road to a Healthier Future. Scotland.

Schikowski., Sugiri., Ranft., Gehring., Heinrich., Wichmann., Kramer 2007. Does respiratory health contribute to the effects of long-term air pollution exposure on cardiovascular mortality? *Respiratory Research*. 8.pp20.

Šenitková, I.2000. Indoor Air Quality in Housing Units. *Proceeding of the XXVIII World Congress on Housing: Challenges for the 21st century.*

Seba, 2017. *Rethinking Transportation 2020-2030*. [online]. Available from: https://static1.squarespace.com/static/585c3439be65942f022bbf9b/t/591a2e4be6f2e1c13df930c5/1494888038959/RethinkX+Report_051517.pdf (accessed on 16th August 2017).

Semenza., Wilson., Parra., Bontempo., Hart., Sailor., George. 2008. Public perception and behavior change in relationship to hot weather and air pollution. Environmental Research. 107. pp401-411.

Sexton,A.2011. *Responses to air quality alerts: do Americans spend less time outdoors.* [online]. Available from: https://conservancy.umn.edu/bitstream/handle/11299/139514/Sexton_umn_0130E_13012.pdf?sequence=1. (accessed on 1st August 2017)

Shekarrizfard,M., Faghih-Imani., Crouse.,Goldberg., Ross., Eluru., Hatzopoulou. 2016. Individual exposure to traffic related air pollution across land-use clusters. *Transportation Research.* 46. Pp339-350.

Shusky, J. 1966. Public awareness and concern with air pollution in the St. Louis metropolitan area. *Journal of the Air Pollution Control Association*. 16. pp72-76.

Shendell., Rawling., Michal., Foster., Bohlke., Edwards. 2007. The Outdoor Air Quality Flag Program in Central California: A School-Based Educational Intervention to Potentially Help Reduce Children's Exposure to Environmental Asthma Triggers. *Journal of Environmental Health.* 70 (3) pp28-31.

Shooter, D., Brimblecoombe, P. 2008. Air Quality Indexing. *International Journal on Environmental Pollution.* 36 (1-2) 305-323.

Simone., Eyles., Newbold., Kicthen., Williams. 2012. Air Quality in Hamilton: Who is concerned? Perceptions from Three Neighbourhoods. *Social Indicators Research.* 108 (2) pp239-255.

Sinton,P., McMurray,I., Brownlow,C., 2014. SPSS Explained. 2nd Edition. East Sussex: Routledge.

Simpson., Williams., Best., Morgan., Denison., Hinwood., Neville., Neller. 2005. The short-term effects of air pollution on daily mortality in four Australian cities. *Australian and New Zealand Journal of Public Health*, 29(3)pp205–212.

Skene., Gent., McKay., Belanger., Leaderer., Holford. 2010. Modelling effects of traffic and landscape characteristics on ambient nitrogen dioxide levels in Connecticut. *Atmospheric Environment.* 44 (39) pp 5156-5164.

Smallbone, K.,2010. *Individuals' interpretation of Air Quality Information*. DEFRA. [online] Available from: http://ukair.defra.gov.uk/reports/cat14/1210261052_Individuals_interpretation_of_air_quality_information_follow-up_invesigation.pdf (accessed on 31st July 2017).

Smallbone, K., 2012. *Individuals Interpretation of Air Quality Information.* [online]. Available from: https://uk-air.defra.gov.uk/assets/documents/reports/cat14/1210261047_Individuals_interpretation_of_air_quality_information_customer_insight_&_awareness_study.pdf (accessed on 29th May 2017).

Solazzo., Cai., Vardoulakis. Modelling wind flow and vehicle-induced turbulence in urban streets. *Atmospheric Environment.* 42. Pp4918-4931.

Stanfield, 2015. Noise effects on health in the context of air pollution exposure. *International Journal of Environmental Research and Public Health.* 112. Pp12737-12760.

Steinle., Reis., Sabel., 2013. Quantifying human exposure to air pollution: moving from static monitoring to spatiotemporally resolved personal exposure assessment. *Science of Total Environment.* 443.pp184-193.

Steinle., Reis., Sabel., Semple., Twigg., Braban., Leeson., 2015. Personal exposure monitoring of PM2.5 in indoor and outdoor microenvironments. *Science of the Total Environment.* 508.pp383-394.

Steffens.,Heist., Perry., Isakov., Baldauf.,Zhang. 2014. Effects of roadway configurations on near-road air quality and the implications on roadway designs. *Atmospheric Environment.* 94.pp74-85.

Stroh., Rittner., Oudin., Ardö., Jakobsson., Björk., Tinnerberg. 2012. Measured and modeled personal and environmental NO2 exposure. *Public Health Metrics.* 10.pp 1478-7954.

Staddon., Cycil., Gouldon., Leygue., Spence. 2016. Intervening to change behaviour and save energy in the workplace. A systematic review of available evidence. *Energy Research and Social Science.* 17. Pp30-51.

Steinle., Reis., Sabel., Semple., Twigg., Braban., Leeson., Heal., Harrison., Lin., Wu. 2015. Personal exposure monitoring of PM2.5 in indoor and outdoor microenvironments. *Science of the Total Environment.* 508. pp383-394.

Speak., Rothwell., Lindley., Smith.2012. Urban particulate pollution reduction by four species of green roof vegetation in a UK city. *Atmospheric Environment.* 61.pp283-293.

Su., Apte., Lipsitt., Gonzales., Beckerman., Nazelle., Sangrador., Jerrett., 2015. Populations potentially exposed to traffic-related air pollution in seven world cities. *Environment International.*78.pp82-89.

Su., Jerrett., Meng., Pickett., Ritx., 2015_b. Integrating smart-phone based momentary location tracking with fixed site air quality monitoring for personal exposure assessment. *Science of the Total Environment.* 506-507.pp518-526.

Symons,K., Leksmon,S., Hayes,E., Chatterton,T., Longhurst,JWS. 2007. Air Quality Management in Auckland, New Zealand. Journal of Ecology and Environment. 101.196-179.

Tabaku., Bejtja., Bala., Toci., Resuli. 2011. Effects of air pollution on childrens pulmonary health. *Atmospheric Environment.* 45 (40) pp7540-7545.

Taj., Jakobsson., Stroh., Oudin. Air pollution is associated with primary health care visits for asthma in Sweden: A case-crossover design with a distributed lag non-linear model. *Spatial and Spatio Temporal Epidemiology.* 17. Pp37-44.

Taylor., McMillan. 2013. *The Canadian air quality health index. In: Air quality management: Canadian perspectives on a global issue*.Springer, Netherlands, pp. 351-363.

Tartakovsky., Baibikov., Czerwinski., Gutman., Kasper., Veinblat. 2013. In-vehicle particle air pollution and its mitigation. *Atmospheric Environment.* 64. Pp320-328.

Tetreault., Perron., Smargiassi. 2013. Cardiovascular health, traffic related air pollution and noise: are associations mutually confounded? A systematic review. *International Journal of Public Health.* 58 (5) pp649-666.

Temam., Burte., Adam., Anto., Basangna., Bousquet., Carsin., Galobardes., Keidel., Künzli. 2017. Socioeconomic position and outdoor nitrogen dioxide (NO2) exposure in Western Europe: A multi-city analysis. *Environmental International.* 101. Pp117-124.

Thiering., Heinrich. 2015. Epidemiology of air pollution and diabetes. *Trends in Endocrinology and Metabolism.* 26 (7). Pp 384-394.

Tilling,S., Raby,S., 2017. *Meeting EU air quality standards – is the UK blowing hot and cold?* [online]. Available from: https://www.burges-salmon.com/news-and-insight/legal-updates/meeting-eu-air-quality-standards-is-the-uk-blowing-hot-and-cold/ (accessed on 29th June 2017).

Tiwary., Coll. 2010. *Air Pollution Measurement, Modelling and Mitigation*. Rutledge. London.

Tong., Chen., Malkawi., Adamkiewicz., Spengler., 2016. Quantifying the impact of traffic-related air pollution on the indoor air quality of a naturally ventilated building. *Environment International.* 90.pp138-146.

Transport for London., 2014. *Improving the health of Londoners: Transport Action Plan.* [online]. Available from: https://www.tfl.gov.uk/cdn/static/cms/documents/improving-the-health-of-londoners-transport-action-plan.pdf (accessed on 21st May 2014).

Tu, J., Tu, W., Tedders, S. 2016. Spatial variations in the associations of term birth weight with ambient air pollution in Georgia, USA. *Environment International.* 92-93. Pp146-156.

Unal, Y.S., Toros, H., Deniz, A. and Incecik, S.2011. Influence of meteorological factors and emission sources on spatial and temporal variations of PM10 concentrations in Istanbul metropolitan area. *Atmospheric Environment*.45.pp5504-5513.

United Nations, 2017. *Report of the Special Rapporteur on the implications for human rights of the environmentally sound management and disposal of hazardous substances and wastes on his mission to the United Kingdom of Great Britain and Northern Ireland*. [online]. Available from: http://www.srtoxics.org/wp-content/uploads/2017/09/Final-UK-mission-report.pdf (accessed on 25th September 2017).

University of York, 2015., Indoor Air Pollution. [online]. Available from: https://www.york.ac.uk/environment/postgraduate/msc-dip-environmental-science-and-management/indoor-pollution/ (Accessed on 26th May 2015).

US Environmental Protection Agency, 2015. *Criteria Air Pollutants*. [online]. Available from: https://www.epa.gov/sites/production/files/201510/documents/ace3_criteria_air_pollutants.pdf (accessed on 3rd March 2016).

Valero., Aguilera., Llop., Esplugues., de Nazelle., Ballester., Sunyer. 2009. Concentrations and determinants of outdoor, indoor and personal nitrogen dioxide in pregnant women from two Spanish birth cohorts. *Environmental International.* 35 (8). Pp1196-2201.

Vallejos A. and Oñate M. 2013. Comunicación de riesgos ecológicos: el caso de la contaminación atmosférica en dos ciudades intermedias del sur de Chile. *Journal of Environment International*. pp59-75.

van den Elshout, S., Léger, K.,Nussio, F., 2008. Comparing urban air quality in Europe in real time: A review of existing air quality indices and the proposal of a common alternative. *Environment International*. 34(5) pp720-726.

Vanos, J.K., Cakmak, S., Bristow, C., Brion, V., Tremblay, N., Martin, S.L. and Sheridan, S.S. 2013. Synoptic weather typing applied to air pollution mortality among the elderly in 10 Canadian cities. *Environmental Research*. 126.pp66-75.

Vehicle Certification Agency., 2017. *Cars and Air Pollution.* [online]. Available from: http://www.dft.gov.uk/vca/fcb/cars-and-air-pollution.asp (accessed on 10th October 2017).

Vehicle Certification Agency., 2018. *Fuel Efficient Driving Tips.* [online]. Available from: http://www.dft.gov.uk/vca/fcb/smarter-driving-tips.asp (accessed on 26th April 2018).

Villeneuve., Johnson., Pasichnyk., Lowes., Kirkland., Rowe. 2012. Short term effects of ambient air pollution on stroke. Who is most vulnerable? *Science of the Total Environment.* 430. Pp193-201.

Vos., Maiheu., Vankerkom., Janssen. 2013. Improving local air quality in cities: to tree or not to tree? *Environmental Pollution.* 183.pp113-122.

Wall, G., 1974. Public response to air pollution in Sheffield, England. *International Journal of Environmental Studies.* 5, pp 259-270.

Wang., Chen., Wan., Zhoa. 2015. Experimental Investigation on Indoor/Outdoor PM2.5 Concentrations of an Office Building Located in Guangzhou. *Procedia Engineering.* 121. Pp333-340.

Wang.,Fallah-Shorshani., Xu.,Hatzopoulou. 2016. Characterizing near-road air pollution using local-scale emission and dispersion models and validation against in-situ measurements. *Atmospheric Environment.* 142.pp452-464.

Wang, Y., Sun, M., Yang,X.,Yuan,X., 2016. Public awareness and willingness to pay for tackling smog pollution in China: a case study. *Journal of Cleaner Production*. 112 (2) pp.1627-1634.

Wakefield, S. E., Elliott, S. J., Cole, D. C.,Eyles, J. D. 2001. Environmental risk and (re) action:air quality, health, and civic involvement in an urban industrial neighbourhood. *Health & place*. 7(3) pp163-177.

Walliman, N., 2011. Your Research Project: Designing and Planning your work. 3rd Edition. London: SAGE.

Wall, G. (1974). Public response to air pollution in Sheffield, England. *International Journal of Environmental Studies*. 5. pp.259-270.

Wartenberg., 2009. Some considerations for the communication of results of air pollution health effects tracking. *Air Quality, Atmosphere and Health*. 2(4) pp207-221.

Wellbeing of Future Generations (Wales) Act. 2015. London. HMSO.

Welsh Government., 2016. Consultation Document: Local Air Quality and Noise Management in Wales. Wales.

Welsh Government., 2017. Local Air Quality and Noise Management in Wales. [online]. Available from: https://consultations.gov.wales/sites/default/files/consultation_doc_files/wg31252_e_final.pdf (accessed on 24th May 2017).

Wen., Juan., Yang., 2017. Enhancement of city breathability with half open spaces in ideal urban street canyons. *Building and Environment.* 112.pp332-336.

Westergaard., Gehring., Slama., Pederson. 2017. Ambient air pollution and low birth weight - are some women more vulnerable than others? *Environmental International*. 104. Pp146-154.

Willett, E. 2011. Assessing the perceptions of environmental pollutants, health, and nutrition behaviour to improve risk communication in Kentucky. [online]. Available from: http://uknowledge.uky.edu/gradschool_theses/48 (accessed 1st August 2017).

Wiggins, A.,Crowston, K. 2011. From conservation to crowdsourcing: A typology of citizen science. 44th Hawaii International Conference on in System Science. pp. 1-10. IEEE.

Williams,B., Barnes,J., Chatterton,T., Hayes,E., Longhurst,JWS. 2016. A critical review of the robustness of the UK governments air quality plan and expected compliance dates. WIT Transactions on Ecology and the Environment, 207.1-9.

Williams., Barrowcliffe., Laxen., Monks. *Review of Air Quality Monitoring in DEFRA.* King College London. London.

World Health Organisation., 2017. Breathe Life. Clean Air. Healthy Future. [online]. Available from: http://www.who.int/sustainable-development/news-events/breath-life/en/ (accessed on 12th October 2017).

World Health Organization. 2014. *Combined or multiple exposure to health stressors in indoor built environments.* WHO Regional Office for Europe, Copenhagen, Denmark.

World Health Organisation.,2016. Ambient (outdoor) air pollution and health fact sheet. [online] Available from: http://www.who.int/mediacentre/factsheets/fs313/en/ (accessed on 14th December 2016).

World Health Organisation. 2013. Review of evidence on health aspects of air pollution – REVIHAAP Project. [online]. Available from: http://www.euro.who.int/__data/assets/pdf_file/0004/193108/REVIHAAP-Final-technical-report.pdf (accessed on 2nd August 2017).

World Health Organisation/,2012., *Diesel engine exhaust carcinogenic*. [online]. Available from: http://www.iarc.fr/en/media-centre/pr/2012/pdfs/pr213_E.pdf (accessed on 20th May 2015).

Woodfield, N.K., Longhurst, J.W.S., Beattie, C.I., Laxen, D.P.H., 2003. Critical evaluation of the role of scientific analysis in UK local authority AQMA decision-making. Sci. Total Environ. 311, 1–18.

Woodward., Levine. 2016. Minimizing air pollution exposure: A practical policy to protect vulnerable older adults from death and disability. *Environmental Science and Policy.* 56. Pp49-55.

Wong., Kan., Qian. 2008. Public health and air pollution in Asia (PAPA): a multicity study of short-term effects of air pollution on mortality. *Environmental Health Perspectives*. 116(9)pp1195–1202.

Wu.,Wilhelm., Chung., Ritz. 2011. Comparing exposure assessment methods for traffic-related air pollution in an adverse pregnancy outcome study. *Environmental Research.* 111.pp685-692

Xu., Chi., Zhu. 2017. Concern or apathy: the attitude of the public toward urban air pollution. *Journal of risk research.* 20 (4). pp482-498.

Yli-Pelkonen.,Setälä., Viippola.,2017. Urban forests near roads do not reduce gaseous air pollutant concentrations but have an impact on particles levels. *Landscape and Urban Planning.* 158.pp39-47.

Zak., Melaniuk-Wolny., Widziewicz., 2017. The exposure of pedestrians, drivers and road transport passengers to nitrogen dioxide. *Atmospheric Pollution Research.* 8 (4). Pp781-790.

Zartarian., Ott., Duan.,2007. Basic Concepts and Definitions of Exposure and Dose. *Exposure Analysis.* Taylor & Francis, Boca Raton pp. 33-64.

Zhang.,Gu., Cheng., Shen.,Dong., Lee. 2012. Measurement of diurnal variations of PM2.5 mass concentrations and factors affecting pollutant dispersion in urban street canyons under weak-wind conditions in Xi'an. Aerosol Air Quality Research. 12. Pp1261-1268.

Zhang., Xu., Zong., Tang, Liu., Wang., 2015. Influence of Meteorological Conditions on Pollutant Dispersion in Street Canyon. *Procedia Engineering.* 121.pp899-905.

Zhang., Arens., Pasut. 2011.Air temperature thresholds for indoor comfort and perceived air quality. *Building Research and Information*. 39. pp134-144.

Zhang., Wang., Hao., Chao, Li. 2016. Air pollution and control action in Beijing. *Journal of Cleaner Production.* 112. Pp1519-1527.

Zheng, M.E. Kahn, W. Sun, D. Luo (2013). Incentivizing China's Urban Mayors to Mitigate Pollution Externalities: the Role of the Central Government and Public Environmentalism. NBER Working Paper. p. 18872

Appendix

Appendix 1 – Study 1 Questionnaire

Section 1: General

1) **Please indicate your gender:** Male ☐ Female ☐

2) **Please state the number of people in your household:** _____

3) **Please state the number of years you have lived at your current address:** _____ Years

4) **Please indicate the type of heating in the property:** Oil ☐ Gas ☐ ☐ Other

5) **Please indicate the type of cooking appliance:** Gas ☐ Electric ☐ ☐ Both

6) **Do any members of the household smoke?** Yes ☐ No ☐

7) **On average, how many hours do you spend in your property a day during the week**? (0-24hrs)
_____hrs

8) **On average, how many hours do you spend in your property a day at the weekend**? (0-24hrs)
_____hrs

Section 2

9) **Below is a table with potential concerns you may have with the area you live. Please rank the top 3 concerns which you have**

Possible Concerns	**Rank your top 3 concerns (1 being the highest)**
Litter	
Traffic Congestion	
Vandalism	
Air Pollution	
Noise	
Dog Fouling	
Housing conditions	

Crime	

10) How would you rate the air quality in your area?

(Please circle your answer)

1	2	3	4	5
Very Bad	Bad	Neither good or bad	Good	Very good

11) To what extent are you concerned about air pollution in your area?

1	2	3	4	5
Not Concerned				Very Concerned

12) In your opinion, does air quality affect health?

1	2	3	4	5
Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree

13) Indicate in the table below if you think air pollution could contribute to any of the following health problems.

	Yes	No	Don't Know
asthma			
lower life expectancy			
brain tumour			
heart disease			
reduced lung function			
lung cancer			
diabetes			
stroke			
kidney damage			

14) How would you describe the traffic levels on the road you live on?

Light ☐ Average ☐ Heavy ☐

15) What is an Air Quality Management Area?

(Please tick **1** option which you believe gives the best definition)

- An area where air quality objectives have not or are not likely to be met ☐

- An area where road traffic levels are monitored and managed ☐
- An area where you are not allowed to burn coal ☐
- An area where air quality is monitored ☐

16) Is your home currently within an Air Quality Management Area?

Yes ☐ No ☐ Don't Know ☐

17) Does the air quality outside affect the air you breathe inside your home?

Yes ☐ No ☐

Section 3

Q14) Please complete this table on the current health status of your household.

Resident	Age	Do you have any of the following respiratory illnesses?						How often do the symptoms occur? (Daily, weekly or rarely?)	How many years have you had these symptoms?	Since living at this property have your symptoms got worse (w) or better (b)?
		Asthma	Lung Disease	Lung Cancer	Reduction in Lung Function	Wheezing	Shortness of breath/ breathing difficulties			
1										
2										
3										
4										
5										
6										

Resident	Age	Do you have or have had any of the following illnesses?						How often do the symptoms occur? (daily, weekly or rarely)	How many years have you had these symptoms?	Since living at this property have your symptoms got worse (w) or better (b)?
		Hypertension	Cardiovascular Disease	Stroke	Diabetes	Chest pains or angina	Cancer			
1										
2										
3										
4										
5										
6										

18) The next study as part of this research will involve monitoring the levels of air pollution in this area.
Please indicate if you would be willing for air quality monitoring to be completed in your home? The monitoring will involve the placing of a diffusion tube (similar to a test tube on the outside of your property and in one room indoors. The tube will be left for 1 month and then collected for analysis. You will be given the results of monitoring at your property.

Yes ☐ No ☐

If yes,
Name _____
Address_____
Telephone No: _____

Thank you very much for completing this questionnaire and participating in the research. If there are any additional comments which you would like to make, please use the space below.

_____
_____
_____

Appendix 2 – Information Sheet

Monitoring Results

Thank you for your participation in our recent research on air quality. The results of the monitoring from your property have been analysed and are explained below.

The government developed an Air Quality Strategy for England, Wales and Northern Ireland which contains objectives for levels of air pollution. The annual average objective for outdoor nitrogen dioxide is **40 µg m-3**. The monitoring results from your property are:

Indoor level of Nitrogen Dioxide –**7.4** µg m-3

Outdoor Level of Nitrogen Dioxide- **61** µg m-3

It is evident from the results that your property provides a good level of protection from the levels of outdoor air pollution. Although the levels of outdoor air pollution exceed the annual objective for nitrogen dioxide, the indoor level indicates that your property provides good protection from exposure to high levels.

If you are concerned regarding the pollution in your area and would like further advice the following sources of information are available.

- Additional information on levels of air pollution in Northern Ireland and the current legislation can be found on the following website www.airqualityni.com
- DEFRA have a free phone automated telephone service providing information on air pollution levels- 0800 55 66 77
- Air Aware is an SMS air pollution alert for Northern Ireland from the DOE. Subscribe to the 'Air Aware' service by texting AIR to 67300 to receive these alerts. Text messages to the service will be charged at your normal standard rate and alerts are received free of charge
- For further information on monitoring and management of air pollution in your area contact your local council

Appendix 3- Interview Schedule

Local Authority Interview Schedule

AQMA

- Currently how many automatic monitoring and passive monitoring sites are within your district?
- What method is used to determine where to site automatic and passive monitors? How often is this reviewed/changed?
- Are AQMA's declared in your area based on monitoring data, modelled data or combination of both?
- How are the boundaries of the Air Quality Management Area decided upon?

- Are there any internal/external departments which you consult with? Any stakeholder meetings or is contact only via email? Are meaningful contributions made/ Is it beneficial?
- Which stakeholders are involved in the development of the AQAP?
- How is the Air Quality Action Plan disseminated among the relevant departments?

- How is the progress of the AQAP measured and how often?
- Of the (number of measures from action plan) measures identified, how many measures have been actioned, partially actioned or not implemented?
- How would you describe the level of commitment from the various stakeholders to the development and implementation of the action plan?
- Have measures led to a reduction of N02?

- Do you have access to the necessary resources (time, money etc) to fully complete your responsibilities under LAQM?
- Is there political support for air quality measures/considerations? Can it be a barrier?
- How would you rate the overall success of the AQAP?
- Do you have any suggestions as to how the AQAP development and implementation process might be improved?
- Scotland and Wales seem to be moving towards a more general improvement in air quality rather than focusing on specific AQMAs. Do you think this approach would be more successful in reducing air pollution levels and human exposure?
- In Environmental Health, the core focus is on health and well- being. Do you think LAQM adequately considers the health of those exposed to air pollution?

Training

- Do you have adequate training in relation to carrying out your duties for LAQM?
- Do you feel developing remediation measures is within the remit of environmental health?
- Do you think the full responsibility of LAQM should lie within EH?
- Do you have the necessary powers to implement change in relation to air pollution reduction measures?

Public Information

- What information is currently available to the public in relation to air pollution?
- Do you think the amount of information available is adequate?
- Do you think the general public are aware of the current levels of air pollution and its potential impact on health?

Do you have any further information you would like to add regarding Local Air Quality Management?

Resident Interview Schedule

1) Who would you contact if you were concerned or wanted more information on air pollution?

2) Are you aware of any information available in relation to air pollution?

3) Do you think there is adequate information available to the public on air pollution?

4) What format do you think air pollution information would be best delivered? e.g. letter, website, magazine, newspaper, app, social media etc

5) Are you aware of any action being taken to reduce air pollution from traffic in your area?

    a. If so what action?
    b. Are you satisfied with the action?
    c. If no, do you think more should be done?

Appendix 4 – Monitoring Results

Table 1: Levels of Nitrogen Dioxide measured on Antrim Road, Glengormley

Location: Antrim Road, Glengormley		**Winter Monitoring**		**Summer Monitoring**	
	Distance from Road	**Indoor µg m-3**	**Outdoor µg m-3**	**Indoor µg m-3**	**Outdoor µg m-3**
1	5.187m	7.5	39.5	43.8	43.9
2	2m	5.4	55	24.2	53.4
3	5.4m	10.4	27	18.9	29.9

Table 2: Levels of Nitrogen Dioxide measured on Canal Street, Newry

Location: Canal Street, Newry		**Winter Monitoring**		**Summer Monitoring**	
	Distance from Road	**Indoor µg m^{-3}**	**Outdoor µg m^{-3}**	**Indoor µg m^{-3}**	**Outdoor µg m^{-3}**
1	1.62m	24.4	97.3	24.7	95.5/28.74
2	1.65m	30.6	75.3	28.5	71.3
3	26.72m	15.6	32	17.6	22

Table 3: Level of Nitrogen Dioxide measured on Main Street Dungiven

Location: Dungiven		**Winter Monitoring**		**Summer Monitoring**	
	Distance from Road	**Indoor µg m^{-3}**	**Outdoor µg m^{-3}**	**Indoor µg m^{-3}**	**Outdoor µg m^{-3}**
1	1.5m	7.4	61	8.6	61.4
2	1.742m	8.9	59.4	18.8	56.3
3	0.5m*	9.8	77.5	16.6	82.1
4	1.565m	15	54.8	18.3	49.2
5	3.841m	27.5	45.7	32*	36.7

Table 4: Level of Nitrogen Dioxide measured on Upper Newtownards Road Belfast

Location: Upper Newtownards Road, Belfast		**Winter Monitoring**		**Summer Monitoring**	
	Distance from Road	**Indoor µg m^{-3}**	**Outdoor µg m^{-3}**	**Indoor µg m^{-3}**	**Outdoor µg m^{-3}**
1	21.487m	8.3	28.8	13.3	16.6
2	20.74m	8.1	24.2	11.6	15
3	21.3m	8.3	25.2	9.6	13.9
4	21.3m	11.2	26.7	-	15.3

Table 5: Level of Nitrogen Dioxide measured on Ormeau Road Belfast

Location: Ormeau Road, Belfast		**Winter Monitoring**		**Summer Monitoring**	
	Distance to road	**Indoor µg m^{-3}**	**Outdoor µg m^{-3}**	**Indoor µg m^{-3}**	**Outdoor µg m^{-3}**
1	10.69m	13.2	39.3	15.7	35.3/48.6
2	11.19m	9.3	39.4	11	25.1
3	6.250m	8.4	41.1	11	40.5

Table 6: Level of Nitrogen Dioxide measured on Stockmans Lane Belfast

Location: Stockmans Lane, Belfast		**Winter Monitoring**		**Summer Monitoring**	
	Distance to Road	**Indoor µg m^{-3}**	**Outdoor µg m^{-3}**	**Indoor µg m^{-3}**	**Outdoor µg m^{-3}**
1	23.9m	7.9	33.8	12.6	26
2	23.68m	16.4	51.7	19.4	41.9
3	18.562	13.5	39.2	19.1	41.9
4	10.261m	13.5	39.2	16.8	31.6
5	25.2m	5.6	49.4	17.8	39.3/31.7
6	10.2m	14.8	45.2	23.2	44.2
7	17m	9.7	36.6	12.5	31.4

Table 7: Level of Nitrogen Dioxide Measured on Lonsdale Road Armagh

Location: Lonsdale Road, Armagh		**Winter Monitoring**		**Summer Monitoring**	
	Distance from Road	**Indoor µg m^{-3}**	**Outdoor µg m^{-3}**	**Indoor µg m^{-3}**	**Outdoor µg m^{-3}**
1	25.2m	10.6	23.6	14.2	15.1
2	25.2m	11.8	21.4	11.7	12.3
3	30.21m	6	27.2	7.1	11.6
4	27.562m	22	28.8	14.8	19.6

Appendix 5 – Indoor/ Outdoor Ratio

Location	**Winter**	**Summer**
Glengormley 1	0.19	0.45
2	0.10	0.45
3	0.39	0.63
Newry 1	0.25	0.26
2	0.41	0.40
3	0.48	0.80
Dungiven 1	0.12	0.14
2	0.15	0.33
3	0.13	0.20
4	0.27	0.37
5	0.60	-
Upper Newtownards road 1	0.29	0.80
2	0.33	0.77
3	0.33	0.69
4	0.42	-
Ormeau Road 1	0.36	0.44
2	0.24	0.44
3	0.20	0.27
Stockmans Lane 1	0.23	0.48
2	0.32	0.46
3	0.34	0.46

4	0.34	0.53
5	0.11	0.45
6	0.27	0.40
Armagh 1	0.45	0.94
2	0.55	0.95
3	0.22	0.61
4	0.75	0.76

Appendix 6- Photographs of Study Locations

1) Dungiven

2) Ormeau Road, Belfast

Below: Large evergreen hedge at one property on Ormeau Road

3) Stockmans Lane, Belfast

4) Upper Newtownards Road, Belfast

5) Lonsdale Road, Armagh

6) Canal Street Newry

7) Antrim Road, Glengormley

Appendix 7 – Conference Proceedings

- Lockhart, D., Vaganay., MacIntyre, S., Jospeh, P. (2015). A Meta-analysis Of The Impact Of Traffic-related Air Pollution on Health and The Factors Affecting Exposure. *Air Pollution XIII*. 198. Pp193-204.

- Lockhart, D., Eadie, R., Vaganay, M., MacIntyre, S. 2017. Exposure to Traffic Related Air Pollution in Northern Ireland*. VII-TH International Scientific Conference in Education, Science and Innovation.* Pernik, Bulgaria.